LABORATORY WORK

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THE ELEMENTS

OF

LABORATORY WORK

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A COURSE OF NATURAL SCIENCE

BY

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PREFACE

THE course of work described in the following pages forms an introduction to all branches of Natural Science. The elementary nature of the book has caused me to pay more attention to method than to detail. Every student will need to follow closely and thoughtfully the performance of each experiment, in nearly all cases making his own observations and measurements, in order that the capacity for independent judgment, as well as an interest in original research, may be awakened at the outset. When a fact or law, discovered by means of a student's own personal observation and intelligence, turns out to be very familiar to others more advanced, the value of the research to the student himself is but slightly impaired.

Each section conveys a definite lesson, and care has been taken that they may follow in inductive sequence. It is important that each experiment and each stage of the course be described and reviewed at length in the student's notebook, which should contain many practical details omitted from the text-book, not only lest they should obscure the more important outlines of work, but also because it is intended that some freedom and originality in manipulation should be encouraged. The trials and practical difficulties of the laboratory are too valuable educationally to be set aside by over-help, though it is essential that they should not be too

severe. It may be noticed that while tables are added to show the results of accurate observers, and to give information as to relative magnitudes, the numerical values resulting from the selected experiments have been generally left to be worked out by the students themselves from their own observations. The word *speed* has been used to denote the rate of motion of a particle along its path, in preference to the term *velocity*, which is now generally reserved to designate a quantity having both magnitude and direction, *i.e.* a vector. The sections numbered 3, 7, 12, 13, 14, 15, 24, 25, and 26, together with many of the additional exercises, may be omitted by beginners.

Rooms devoted to practical science, and well equipped, are nowadays considered a necessary part of all public schools and colleges, and this book is simply intended to be used as a handbook in such laboratories. An effort has been made to arrange a practical and progressive course which shall touch upon the chief problems, and point out the main lines of investigation in Natural Science, in preference to an attempt at explaining any one branch in detail. It is also hoped that the course may give some training in that habit of directly appealing to nature, rather than to theories, which is the root of all scientific progress, although unfortunately it is not always made the basis of scientific education, partly from want of time and partly from want of appliances.

A. G. EARL.

TONBRIDGE: 1890.

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THE ELEMENTS

OF

LABORATORY WORK

CHAPTER I

MEASUREMENT OF QUANTITY OF MATTER

1. To Find Equal Quantities of Matter.—1. Use a balance, and counterpoise two pieces of wood, cutting away one or the other with a knife until exact balance is obtained.

2. Counterpoise a piece of wood and a piece of lead.

3. Counterpoise another piece of wood with the lead, and then observe that the two pieces of wood counterpoised by the lead counterpoise one another.

The above exercises show :—

1. That with the same kind of matter, wood, the pieces which counterpoise each other are the same size, or thereabouts ; but different kinds of matter which counterpoise each other are not of the same size.

2. That two bodies counterpoise each other if they each counterpoise a third body ; for these two bodies have been found to act alike under the same conditions—that is, when placed in the same position, and with all the surroundings the same.

Two such pieces of matter are said to be *equal quantities*

of matter, however unequal in size or different in appearance they may be.

Counterpoising one quantity of matter by another will indicate equal quantities of matter only when the instrument used is correct. But by performing two operations as in (2) and (3) we find two quantities of matter which are counterpoised under precisely similar circumstances with a third unchanged quantity of matter (the piece of lead kept in the same pan). There is nothing changed in these two operations except the pieces of wood. Although the balance used may be inaccurate, the same inaccuracy holds for each case, and thus we can make sure that two bodies are equal quantities of matter even with an inaccurate balance.

2. To Compare Two Quantities of Matter.—1. Take several equal quantities of matter, and find how many of them counterpoise with a given piece of wood, cutting away the wood if necessary. It is convenient to use a set of *weights*—that is, a number of bodies so arranged and measured that we can readily make up from them a quantity of matter which shall contain the smallest quantity any required number of times. The need of a large number of equal quantities is thus avoided. Use grams. One gram will be the *standard.*

2. See how many of the same standard quantities of matter are equal to a larger piece of wood, cutting away as before if necessary.

3. Compare similarly two other pieces of wood, but use much smaller standards. Notice that less cutting away, if any, is needed. Use centigrams. A centigram is one-hundredth of a gram. With milligrams or thousandths of a gram the comparison becomes still more accurate.

The above exercises show :—

1. That two quantities of matter can be compared, by seeing how many times each contains a standard quantity.

2. That the standard quantity, if large, does not enable us to measure exactly ; but the smaller the standard, the more exactly can we measure and compare.

3. That the limit of exactness can never be attained, as inequalities will be shown by more delicate balances. The

degree of accuracy should depend upon the object of the comparison.

We see that two operations take place in weighing any substance. The first consists in finding out a quantity of matter which will counterpoise the substance, or which will take its place on the pan and counterpoise equally a third body on the other pan. The second operation needed is to find out how many times this quantity of matter contains the standard quantity. When a set of weights is used the second operation consists in reading the marks or numbers on the several weights required for counterpoise.

When a spring-balance is used the pointer indicates how many times the standard quantity of matter would be required to produce the same elongation of the spring. In this case the counterpoise, or what corresponds, has been made once for all by the maker, and the results marked on the scale. Compare a spring-balance with an ordinary one.

3. To Test the Accuracy of a Set of Weights by the Balance.—Counterpoise a 2-gram weight with shot and paper, then replace it by another. If they contain equal quantities of matter the counterpoise will be maintained. Test the two 10-gram weights similarly, and other equivalents, such as the two 10-gram weights with the 20-gram. Any excess or deficit may be marked, if the comparison has been made with an exact standard, and the balance is reliable.

4. To Investigate the Construction of an Accurate Balance. It is advisable at this stage to learn the necessity of great care in the use of such balances as are used in a laboratory. This may be done by taking to pieces very carefully such a balance s the one illustrated (fig. 1).

1. Note the rest or catch which prevents the knife-edges being worn, by saving them from unnecessary jarring.

2. Compare the balancing of the beam upon its knife-edge, when the pans have been removed, with that of a strip of wood upon a blunt point.

3. Note that the knife-edges supporting the pans enable the matter wherever it may happen to be placed in the pan to

act at the same point on the beam (namely, at the knife-edge itself).

4. Observe the use of the pointer and scale.

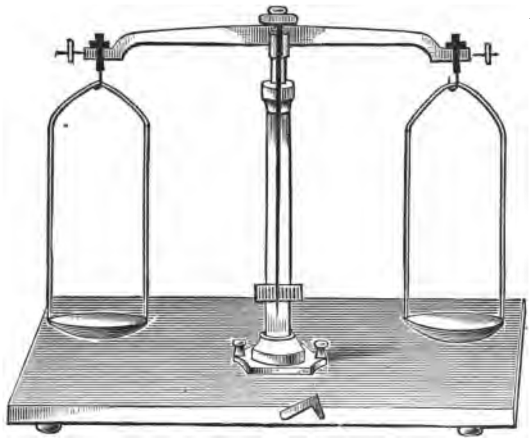


Fig. 1.

Additional Exercises and Questions.

1. Construct a set of fractions of a gram from platinum foil and aluminium foil. Use a pair of scissors for cutting away, and impress the value on each when correct.

2. How may equal quantities of matter be determined on a balance which has unequal arms? What arguments may be used in support of your method?

3. Describe exactly what is meant by saying that a given body weighs 3·3 grams, and give the operations by which this knowledge of the body is obtained.

4. How many milligrams are contained in 103·725 grams? What fraction, vulgar and decimal, of a gram is the quantity 7 centigrams together with 11 milligrams?

5. Why is it best to stop the balance from swinging when the pointer is at the centre of the scale, and why should the weights never be altered when the balance is swinging, or the pans breathed upon when an observation is being made?

6. Which is the best method of judging when there is exact counterpoise—(*a*) by seeing whether the pointer comes to rest at the centre

of the scale, or (*b*) by seeing if it swings an even distance on each side of the centre? Make an observation and explain the result.

7. What kinds of matter should be used for standards in weighing accurately? What is the advantage of aluminium over platinum for small standards? Should weights be cleansed?

5. Measurement of Length and Volume.—1. Find out the length of a given object by seeing how many times a given standard length is contained in it. Use 1 centimetre as a standard. (1 centimetre is one-hundredth of a metre.)

2. Measure the dimensions of a regular-shaped body. Use 1 centimetre as a standard.

3. Measure a given plane area by means of a body of standard area, and also by calculation. Use a square centimetre as standard. A square centimetre is a square of which the side is 1 centimetre.

4. Find out by calculation how many times a given cube is larger than a standard cube. Use as standard a cube of which the side is 1 centimetre.

5. Find out by displacement of water, which readily adapts itself to any shape, how many times a standard cube is contained in an irregular-shaped body. Use a graduated vessel, marking cubic centimetres.

6. Verify the graduation of a burette by weighing the quantities of mercury or water delivered into a weighed vessel. Each division need not be tested. Care is needed in finding when the middle point of the liquid surface is level with the proper mark on the vessel.

The above exercises show that the same methods are used in comparing the lengths and volumes of various bodies as in composing quantities of matter, and that there is the same necessity for a standard length and a standard volume for purposes of comparison.

Precautions in Measuring.—The distance between any two points is found by measuring the number of units of length in the imaginary straight line joining them. In measuring any given distance we have to depend on our eyesight or touch for ascertaining the coincidence of two points or marks. Care must be taken that this coincidence is real.

For determining coincidence of liquid level with a mark on a graduated vessel a reading telescope [or that of the cathetometer] is used when accuracy is needed. The surface of a liquid in a tube is not horizontal. In this case the centre of the surface is observed at each operation.

Sometimes it is not possible to apply a scale directly to a distance, as in measuring the diameter of a sphere. The measurement then takes place indirectly. Another distance, capable of being measured, is adjusted so as to be equal to it, and then measured in its place. The use of callipers and compass will illustrate this method, and show how the sense of touch is used. Compare the results obtained with each of these instruments for a given dimension, such as the diameter of a sphere. The alteration of the dimensions of bodies by change of temperature makes it necessary that measurement should take place under the same conditions of temperature. The length of a metal rod should be taken at different temperatures to illustrate this need.

Additional Exercises and Questions.

1. What are the requisites of a good standard of length?
2. By what processes may lengths be measured?
3. How would you find out if a given standard is correct?
4. What are the advantages generally of the Metric system of measurement?
5. Describe exactly the assumptions made in measuring any dimension of a body, and compare the reasoning used with that used in weighing a body.
6. Measure the distance between two given points which are not connected by matter. State the precautions needed.
7. Measure as accurately as possible by a good scale the value of an inch in centimetres. Suggest methods by which greater accuracy may be obtained.
8. Use a steel scale and show that the graduations vary with the temperature: measure when cold and after heating.
9. Test the graduation of a eudiometer tube by fixing it upright and reading the successive levels caused by the addition of equal quantities of water. The water may be delivered from a burette or a pipette. Mention the precautions which are necessary.

6. Relative Quantities of Matter in Equal Volumes of Different Substances.—1. Compare the quantities of matter in equal volumes of mercury and water, and turpentine. Use a marked beaker or flask, and a balance.

2. Compare the volumes of the above substances when equal quantities of matter are taken in each case. Use a beaker for weighing, and ascertain the volumes by pouring into a graduated vessel. Commence with the turpentine.

3. Compare the volumes contained in equal quantities of brass and water. The volume of a piece of brass is equal to that of the water it displaces, and, by the displacement of water in a graduated vessel, the volume of the brass is easily measured.

4. Taking as unit the quantity of matter contained in a given volume of water, calculate the numbers to be given to equal volumes of other liquids and solids. Refer to the table of densities.

The above exercises show that the appearance and size of a body give no exact information as to the quantity of matter it contains. Bodies vary in density. In order to ascertain the density of a body the volume and quantity of matter are each measured. The volume of a liquid is easily measured as it adapts itself to any required shape, but the volume of an irregular-shaped solid is less easy. It may be measured by displacement of a suitable liquid in a graduated vessel. It is a great convenience to compare all substances by reference to a common standard, and water of a fixed density is selected. Then the numbers, called specific gravities, which tell how much denser various substances are than water, show their densities relatively to one another. But it is more systematic to express the density of a body by the number of units of mass in unit of volume. A body which has four units of mass in unit of volume is twice as dense as one containing two units of mass in unit of volume, and so on.

It must be remembered, when we speak of equal quantities of different kinds of matter, that we do not refer to equal volumes, but to such volumes as contain what we have agreed to call equal quantities of matter. Later on we shall add to our knowledge of equal quantities of matter.

Additional Exercises and Questions.

1. Assuming that the density of brass is 8—that is, that 1 cubic centimetre contains 8 grams of matter—find the volume of a given piece of brass by weighing and calculating. Compare the result with that obtained by measuring the volume of water displaced by the brass.

2. Compare the densities of lead and tin by weighing, and determining volumes by displacement of water.

3. Suggest methods of finding both the apparent and real density of porous bodies.

4. How would you find the density of copper sulphate—a substance which dissolves in water?

5. Mention the various precautions which must be taken during observations of density.

6. What hypothesis can you suggest in explanation of the difference in density observable among various kinds of matter?

7. Principles of Systematic Measurement.—We have discussed in the preceding sections concrete quantities of different kinds—quantity of matter, quantity of length, quantity of area, quantity of volume, and quantity of density.

By direct observation we have been able to decide when two given quantities of the same kind are equal. We have then seen how many times a given standard quantity is to be taken to make up a quantity equal to the quantity being measured—that is, we obtain numerical values, or *numbers expressing the magnitude* of any concrete quantity. All that we can say of any quantity is that it is equal to so many times a quantity of the same kind selected as a standard, and all that we can directly observe is equality, or inequality, in quantity.

The standard quantity of matter, or the *unit of mass*, now used in all physical measurements is called a *gram*.

The standard quantity of length, or unit of length, now used is called a centimetre.

For convenience in exact weighing, sets of weights are used—*i.e.* various pieces of brass and aluminium, carefully adjusted by the maker, so as to contain certain multiples and fractions of the quantity of matter in a gram, and arranged as follows:—

100 grams	5 grams	0·5 grams	0·05 grams	0·005 grams
50 „	2 „	0·2 „	0·02 „	0·002 „
20 „	2 „	0·1 „	0·01 „	0·002 „
10 „	1 „	0·1 „	0·01 „	0·001 „

Investigation of these masses will show that all quantities of matter not exceeding 201 grams, and not less than ·001 gram, are represented to within ·001 gram. It may happen that a quantity of matter to be weighed differs in quantity from any possible collection of the above weights; but it will differ by a quantity less than ·001 gram, and this may be negligible, or the balance may be unable to mark it. Some balances, however, measure within smaller quantities. Larger quantities are measured by larger standards; and names are given to multiples and fractions of a gram as seen in the table below, which represents a portion of the metric system of measurement.

A mass of 1,000 grams is called 1 kilogram
(equivalent to 2·2054 lbs. avoirdupois).
A mass of ·1 gram is called 1 decigram.
„ „ ·01 „ „ 1 centigram.
„ „ ·001 „ „ 1 milligram.

For convenience in measuring quantity of length, or distance between two fixed points, a scale is used. This may be looked upon as corresponding with a set of weights. It is a body of suitable material and form, marked so that the distance from any mark to the next is equal to a centimetre, or, if greater accuracy is required, to ·1 centimetre. Numbers are written at intervals for readiness in reading the total number of centimetres. If large distances have to be measured, a centimetre is too small a standard; while for very small distances the centimetre has to be subdivided, in the same manner as the gram is subdivided for accurate weighing. The following table gives the names of lengths, derived from the centimetre, according to the metric system:—

A length of 10 centimetres is called a decimetre.

A length of 10 decimetres or 100 centimetres is called a metre (equals 39·37 inches).

A length of 1,000 metres or 100,000 centimetres is called a kilometre.

A length of ·1 centimetre or ·01 decimetre or ·001 metre is called a millimetre.

The numerical value—*i.e.* the number expressing the magnitude of any quantity of matter or of any distance—shows its relation to a magnitude of the same kind selected as unit.

Thus if M denotes a definite quantity of matter, and L a definite distance, and m and l the respective units, then $\frac{M}{m}$ and $\frac{L}{l}$ give the numerical values of these quantities.

It is seen that numerical values vary directly as the quantities, and inversely as the units with which the quantities are compared. In other words, as the quantity increases the numerical value increases, but as the unit increases the numerical value diminishes.

In practice the magnitudes of most quantities are expressed by a number, followed by the name of the units used—*e.g.* 20 centimetres, 3 grams. The necessity for the names arises from the use of various systems of measurement. For example, distances are, for other purposes, measured by inches, feet, yards, miles, &c., and quantities of matter by ounces, pounds, tons, &c. If one system were universal, numbers alone would denote the magnitudes of physical quantities. We shall afterwards see that all physical quantities, however complex in their nature, may be measured by the use of three *fundamental* units of length, mass, and time. This system is called the centimetre-gram-second, or C.G.S. system. It will be seen that all quantities are brought to a common scale by use of this system.

Having selected the centimetre as the unit of length, it is necessary, in order to secure uniformity, to take as the unit of area the quantity contained by a square, each side of which is a centimetre; and for unit of volume that quantity contained by a cube, each side of which is a centimetre. A

volume equal to that of 1,000 cubic centimetres [written 1,000 c.c.] is called a *litre.*

The final authority for the unit quantity of matter in the C.G.S. system, and the standard by which it must be determined, directly or indirectly, is the *Kilogramme des Archives*, a piece of platinum adjusted by Borda.

The gram is ·001 of this piece of platinum.

All distances must be compared, directly or indirectly, with the distance between the ends of a rod of platinum when it is at the temperature of melting ice. This is the standard *mètre* made by Borda in 1795. The centimetre is equal to ·01 of this distance.

The metre was selected as being the ten-millionth part of a quarter of the earth's circumference, so that all lengths might be compared with the circumference of the earth, a length looked upon as permanent, and hence always capable of being redetermined. That the earth's circumference should be commonly referred to as the standard is, however, impossible, and the alternate authority is now the length of the platinum rod made by Borda.

Having fixed on a distance and called it a metre, a piece of platinum was prepared containing the same quantity of matter as a cubic decimetre of pure water at 4° C. This was called a 'kilogramme.' Hence a cubic centimetre of such pure water would have a mass of 1 gram. This process was adopted with the intention of being able to re-establish the unit of mass, if necessary, from the unit of length, but this is practically very difficult, and moreover the supposed relation is only approximate. Hence both the metre and kilogramme are arbitrary standards.

It is part of the same uniform system to take a density of 1 gram per cubic centimetre as unit of density. It was intended to make the density of water unit, and it is very nearly so, for it contains approximately the unit quantity of matter in the unit volume. A body which contains 2 grams per c.c. would have a density denoted by 2, and so on.

The number expressing the magnitude of a given density is determined by finding the number of units of mass it

contains, and also the number of units of volume. Then the first number, divided by the second, gives the number expressing the density, or—

$$D = \frac{M}{V}$$

when D equals numerical value of density
,, M ,, ,, ,, ,, mass
,, V ,, ,, ,, ,, volume

The unit of volume, however, is derived from the unit of length; for if l denote the unit of length, l^2 denotes the unit of area, and l^3 that of volume. Hence we may write $d = \frac{m}{l^3}$ and perceive that d, the unit of density, is derived from the fundamental units of length and mass.

If a different system of units is used in measuring density, then the numerical values will be found from the following equation :—

$$\frac{D}{d} = \frac{\frac{M}{m}}{\frac{L^3}{l^3}} \quad \text{or} \quad \frac{D}{d} = \frac{Ml^3}{mL^3}.$$

Here D, M, and L stand for the respective concrete quantities, and d, m, l for the units adopted.

8. Relation of Areas to Linear Dimensions.

A square, the side of which has a units of length, contains a^2 units of area.

A rectangle, the sides of which have respectively a and b units of length, contains ab units of area.

A circle, the radius of which has r units of length, contains πr^2 units of area.

A cube, the edge of which has a units of length, contains $6a^2$ units of area.

A sphere, the radius of which has r units of length, contains $4\pi r^2$ units of area.

π stands for 3·14159 nearly.

9. Relation of Areas to one another.

English Measures.

1 acre contains 4,840 square yards—*i.e.* a square the side of which is a yard.

1 square yard contains 9 square feet.

1 square foot contains 144 square inches.

Metric Measures.

1 hectare contains 10,000 square metres.

1 square metre contains 100 square decimetres.

1 square decimetre contains 100 square centimetres.

1 square centimetre contains 100 square millimetres.

1 metre = 39·37 inches nearly.

10. Relation of Volumes to Linear Dimensions.

A cube, the edge of which has a units of length, contains a^3 units of volume.

A rectangular parallelopiped, of which the respective edges have a, b, and c units of length, contains abc units of volume.

A sphere, the radius of which has r units of length, contains $\frac{4}{3}\pi r^3$ units of volume.

A circular cylinder, of height h and radius r, contains $\pi r^2 h$ units of volume.

11. Relation of Volumes to one another.

English Measures.

1 cubic yard contains 27 cubic feet.

1 cubic foot contains 1,728 cubic inches.

1 gallon contains 8 pints or 4 quarts.

1 pint contains 34·659 cubic inches.

Metric Measures.

1 cubic metre contains 1,000 cubic decimetres.

1 cubic decimetre contains 1,000 cubic centimetres (c.c.).

1 cubic centimetre contains 1,000 cubic millimetres.

1 cubic decimetre is called a litre.

1 litre contains 1,000 cubic centimetres or 1,000,000 cubic millimetres.

1 litre contains 1·76 pints nearly.

12. Method of Measuring very small Quantities of Matter. Although a carefully constructed balance will readily indicate a difference of 1 milligram (or ·001 gram) between the quantities in the two pans, and although the milligram 'weight' is the smallest quantity of matter which is placed in the pan for the purpose of comparing quantities of matter, yet we have to deal, in chemical measurements, with quantities far more minute than milligrams. In order to obtain this great accuracy of comparison, the operation of weighing is combined with that of solution. When a solid is dissolved in a liquid—for example, salt in water—there are numerous proofs that the solid is evenly distributed through the liquid. A small quantity of the solid is taken and dissolved in a large quantity of the liquid. For example, ·1 gram of common salt may be dissolved in some water in a litre flask, and then more water added until it is full up to the litre mark. A portion of this may be transferred to a burette graduated into cubic centimetres, or even into fifths of cubic centimetres. We may thus be certain how much of the salt is contained in our carefully measured portions of this solution; and we may be certain, by using the more accurately graduated burette, to within the $\frac{1}{50000}$ (or ·00002) of a gram.

13. Methods of Measuring very small Distances.—The Vernier.—Greater accuracy in the measurement of distances between two points is obtained when the ordinary scale is accompanied by a sliding scale, or vernier, which is divided so that n divisions correspond with $n-1$ divisions of the scale. Then each vernier division is $\frac{1}{n}$th smaller than a scale division. If the vernier has 10 divisions, for example, which are equal to 9 of the scale, a vernier division is $\frac{1}{10}$ smaller than a scale division. In use, the vernier is moved until the marked point, or end, is in the proper position for calculating the required dimension. In the diagram (fig. 2) the distance to be measured

is from *a* to *b*, the vernier standing at *b*, between 5 and 6 of the scale. Looking along the scale, it is found that division line 7 of the vernier and 12 of the scale more closely coincide

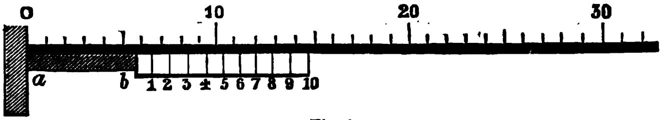


Fig. 2.

than any others. Since each vernier division is $\frac{1}{10}$ less than a scale division, the distance between 5 and *b* is $\frac{7}{10}$ of a scale division—that is, the whole distance is 5 plus $\frac{7}{10}$ or 5·7. With smaller divisions greater accuracy is obtained.

Samples of verniers, for practice in reading, will be found on the barometer, cathetometer, and spectroscope. On the last it is used for reading very small angles.

14. The Micrometer Screw and Spherometer.—A small distance may be very accurately measured by means of screws carefully constructed, so that a given length of the stem contains a suitable number of threads. This micrometer screw works within a corresponding hollow screw.

If the screw has 10 threads in a centimetre, and the hollow screw is fixed, one complete turn of the screw will cause it to advance ·1 centimetre. If the head of the screw takes the shape of a large graduated circle, containing, for example, 200 divisions, then a turn through one of these divisions will cause the screw to advance $\frac{1}{200}$ of ·1 centimetre, or ·0005 centimetre.

In the Whitworth measuring machine a distance may be read to one-millionth of an inch, by a modification of this process.

This method of measurement is illustrated in the use of the spherometer (fig. 3). A three-branched piece of metal stands on three fixed equidistant legs, and a micrometer screw with a large divided circular head moves through the centre, and is read by the aid of a fixed upright scale. The points of the legs and moveable screw are of hard steel, and they are adjusted on a true plane, so that all four are in the same plane

when the divided circle is at zero. Small vertical distances and curvatures are measured by finding the new position of

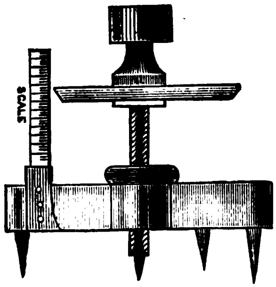


Fig. 3.

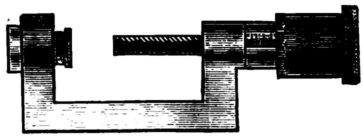


Fig. 4.

contact for all four legs by the sense of touch. The screw-gauge (fig. 4) also illustrates this method of measuring linear distances by the movement of a screw. Measurements should be taken with each instrument.

15. Other Methods of Measuring Density.—When a body is weighed while suspended in water or other liquid, it may be counterpoised by a smaller quantity of matter than when weighed in the air. Experiments show that this apparent loss is exactly equal to the quantity of water or other liquid displaced by the body—*i.e.* to the mass of the volume of the liquid equal to its own volume. In order to determine the density of a body, suspend it by a fibre of silk or by a thin wire to the hook at the end of a balance-beam. Weigh it in this position, and then support a vessel containing water over the pan of the balance, so that the body may now be weighed when immersed in water. Care must be taken that no air adheres to the body when in the water, and that the density of the water at the temperature of observation is used in the calculation, not that of water at the standard temperature (0° C.).

$$\text{Density} = \frac{\text{True mass}}{\text{Apparent loss of mass in water.}} = \frac{\text{Mass}}{\text{Volume.}}$$

By reference to a table of the densities of water at different temperatures, we find the volume of water corresponding to the quantity of matter apparently lost, and this is the same as the volume of the body measured. If the substance to be measured dissolves in water, a liquid which does not dissolve it is used.

If the body does not sink in water, its density must be obtained simultaneously with that of a heavy body, of known density, which will cause it to sink. And a third method is to make such a mixture of two liquids, say alcohol and water, that the body will float in it at any depth. Then find the density of the mixture by direct weighing. This will be the same as that of the body.

Table of Densities.

$D = \frac{M}{V}$ *or units of mass in unit volume at* 0° *C.*

Air	0·00129
Alcohol	0·795
Aluminium	2·50 to 2·67
Brass	7·80 to 8·54
Copper	8·30 to 8·89
Ether	0·716
Gold	19·20 to 19·60
Glass	2·50 to 3·50
Glycerin	1·26
Iron	7·50 to 7·90
Hydrogen	0·0000896
Ice	0·918 to 0·92
Lead	11·07 to 11·40
Nitrogen	0·001256
Mercury	13·596
Oxygen	0·00143
Platinum	21·16 to 21·53
Hydrogen sulphate	1·854
Turpentine	0·870
Sea water	1·026
Pure water at 4° C.	1·000013
Wood	0·4 to 0·9

Additional Exercises and Questions.

1. Calculate the number of cubic millimetres in a cubic inch.

2. If 2 litres of air weigh 2·5854 grams, what is the density of air?

3. If the pitch of a screw is 1 millimetre and its circular head is divided into 100 equal divisions, calculate the linear distance corresponding with a turn of the circle through 73 divisions.

4. Determine the pitch of a screw by direct comparison with a scale, and also by ascertaining its linear movement when turned within a fitted hollow screw.

5. Measure the circumference of a penny by marking it and rolling it along a scale. Then measure its diameter and calculate from it the circumference.

6. Read the height of the barometer by using the vernier.

7. Take several readings of angles by using the vernier on a spectroscope.

8. Ascertain the diameter of a wire by using the screw-gauge.

9. Find the thickness of a microscopic cover-glass by using the spherometer. Also measure several cover-glasses and compare the result with the last observation.

10. How may microscopes be utilised for measuring very small distances?

11. How is a long distance best measured? What difficulties have to be overcome and what precautions are needed?

12. Suggest methods for measuring irregular areas.

13. Compare the densities of several liquids by weighing the same body in each.

14. Observe the alteration of density, when the temperature of water is raised, by showing that the counterpoise obtained when a body is weighed in cold water is not maintained if warm water is substituted for the cold.

15. Suggest a method of determining the density of a body lighter than water. Test your method.

16. How could the density of a gas be found out?

17. What precautions are necessary in determinations of density, and what conditions have to be attended to? Give the observations, in order, which are needed in an exact determination of density in the case of (*a*) a gas, (*b*) a liquid, and (*c*) a solid.

CHAPTER II

OBSERVATIONS OF CHANGE OF POSITION

16. Relative Position.—The simplest kind of change observable in nature is change of position, and the simplest observable instance of this occurs when two material particles change their position with regard to each other. A simpler case cannot be observed. We are unable to perceive a change of position in space except as occurring between two bodies at least, or between two parts of the same body. Two bodies are always needed for the perception of movement, rough or exact measurements being made from one to the other. For this cause we are not conscious of the rapid movement of the earth, except by reference to some other body in space. One or more material bodies, coming under any kind of observation for investigation or measurement, will be called a material system. In investigation of any change, it is important to exclude from the system all unnecessary members, while including all that are essential. All research proceeds by gradually eliminating the non-essential elements of a change, or by including more and more members within the region of measurable change.

The relative positions of two material particles may be represented by a diagram (fig. 5), where the length of the straight line A B drawn from A to B represents the distance of B from A. By agreeing to represent a distance in space of one metre by a length of line of one centimetre, or by any similar agreement, the diagram becomes a plan drawn to scale.

The relative positions of any number of material particles, that is, the configuration of any system, may similarly be represented by ascertaining in this manner the distance of

each from a given origin, and drawing corresponding lines on paper.

We shall now proceed to show that such a representation is only partially true. It describes relative distances only.

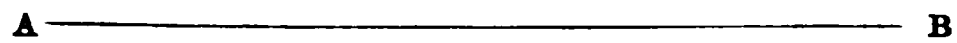


Fig. 5.

17. Means of Defining the Position of a Small Body with regard to a Fixed Point.—It is clear that we know nothing of position except by reference to some point taken as fixed; and, since our description is always relative, it is of no importance to determine the real condition of this point, whether fixed or moving. Our statements and measurements are made on the assumption that the point of reference is fixed, although further investigation might show that the point of reference is far from fixed.

It must not be supposed, however, that the measurement of the linear distance of a body from a point, considered as fixed, completely describes position. It is necessary to state the direction in which the distance has been measured. For example, the circumference of a circle consists of an infinite number of points equidistant from the centre of the circle. And all positions on the surface of a sphere are the same linear distance from the centre of the sphere. Something more than linear distance is needed. We require to know the direction in which the operation of linear measurement has been, or is to be, made.

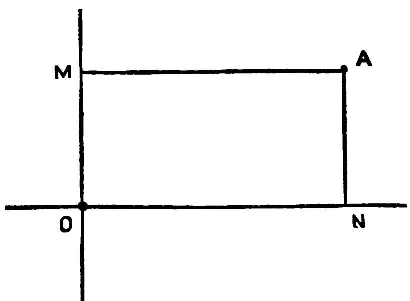


Fig. 6.

An inspection of the diagram (fig. 6) will show that if it be merely a question of the position of the particle A with regard to the point O, each of them being upon this flat sheet of paper, we may understand what is

meant by direction if we draw two straight lines which shall pass at right angles through the point O. Lines A M, A N drawn perpendicularly from A to these lines of reference show by their relative magnitude in what direction A lies with regard to O. It is important to note that our observations do not extend beyond particles, that is, bodies or portions of bodies so small that their dimensions may be neglected. How small such a body need be will depend upon the purpose of the measurements and the accuracy attainable.

18. Observation of Change of Position.—If the position of a particle be observed or measured at different times, and the necessary measurements be not found unchanged, then the particle has undergone a displacement or change of position. The simplest change of this kind which can be observed is the alteration in the linear distance between two particles A and B. If we consider these two bodies entirely by themselves, without reference to any other body, we may represent fully by diagram the amount of displacement during any given interval. All that is necessary is to draw a straight line, A B, representing the linear distance between them at the one instant of time, and another line, *a b*, representing in the same direction the linear distance at the other instant. The difference of the two lines in length taken on the same scale represents the displacement, but only when the straight lines A B and *a b* remain strictly parallel. As to the exact mode of displacement or condition of the particles during the change, such a plan tells us absolutely nothing; and as to whether one alone or both together have undergone an absolute displacement, we are unable to decide. We are unable to say in the simplest case of displacement whether A or B has moved. In other words, we are only aware of displacement as a change in a relation of two bodies at least, that is, we can observe relative displacement alone. If we refer to a third body, and make the necessary measurements, it is true we gain additional knowledge, but an extension of our measurements to a fourth body might disclose further displacements. A little consideration will make clear the connection between our inability to know any-

thing of absolute position and our ignorance of absolute displacement.

19. Further Observations of Position and Displacement.—We have now to consider less simple modes of displacement. We have learnt that position, and consequently change of position, must be measured by reference to something considered as fixed, and further that reference to a single point is not sufficient even when we are limited to a given plane. If we consider the surface of the floor, one side and one end of a rectangular room as fixed, while a body within the room is in motion, a simple experiment will illustrate that the position of that body is completely defined at any moment by measuring its shortest distance from each of these three surfaces. Instead of these surfaces, the roof, other end, and other side might be used with the same completeness of definition, although the actual measurements might differ. But the same result would not follow if two of the surfaces were parallel. The three surfaces are best at right angles to each other. The body under consideration may now be caused to move in three directions, and in three directions only. It may be displaced with regard to one surface only, its distance from the other two remaining unaltered. It may also be displaced with regard to two surfaces at the same time, and, lastly, it may be displaced with regard to three surfaces simultaneously. These three methods include all the possible kinds of displacement, that is, if measurements be taken at two distinct times of the distances from the three surfaces, either one, two, or three may be found to have altered. By taking a number of consecutive observations of these distances and marking the positions in some way, we may construct the path of the body. In common occurrences of displacement a series of rough measurements are made from sight, and, by the aid of memory, the path along which the body has moved may be described. But in every possible case of displacement, the limit of knowledge attainable is that given by three linear measurements from three plane surfaces at right angles to one another. These measurements may be taken at as short intervals of time as possible, and the more frequently they are made the

more completely is the path of the moving body known. Having made such measurements at sufficiently frequent intervals, we shall find that a particle may move :—

1. In a straight line with alteration of distance from one plane.

2. In a straight line with alteration of distance from two planes.

3. In a straight line with alteration of distance from three planes.

4. In a curved line with alteration of distance from two planes.

5. In a curved line with alteration of distance from three planes.

20. Practical Measurement of the Paths of Moving Bodies. The three necessary planes from which measurements of position have to be taken, may be illustrated by three plane pieces of wood, screwed together at right angles, as shown below. For readiness in calculation and measurement these pieces of wood should be covered with paper containing lines ruled at right angles to each other vertically and horizontally on each surface. By this means, the three inner faces are covered with equal squares of, for example, a centimetre in the side ; and if each of the lines so drawn is numbered, the position of a body with regard to any plane is readily perceived. The numbers may be written along the three lines of junction as shown in the figure.

A small body fixed upon a wire, which is curved at the bottom so as to stand, will serve as the body of which the position requires to be defined. Different values result from the measurement as its position is changed. Several observations should be made and recorded. It will be noticed, however, that the distance from one plane, which is the one on which it stands, does not vary from the nature of the support. This may be varied by bending the wire. A little consideration of the model will show that we may get sufficiently accurate results by shutting one eye and looking with the other at the position marked by the body on each surface in succession.

Instead of varying the position of a body we may support a wire, *a b*, as shown in the diagram, in such manner as to represent the path through which an imaginary body has been, or is being, displaced. The position of the wire may be varied in any manner, and it may be made to assume any shape. A number of measurements should be taken of various possible paths.

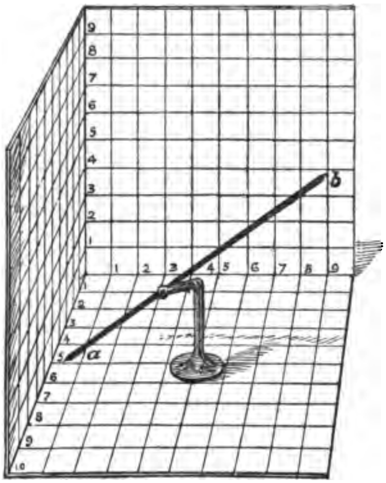


Fig. 7.

If we now introduce an irregular-shaped body of considerable dimensions, it will at once be seen that three linear measurements are not sufficient to define its position. They would in fact define nothing more than the position of that portion of the body from which they were made, and no information would be supplied as to the rest of the body. In order to obtain this information accurately each portion of the body would require to be defined by its distance from the three planes; but if the body is a rigid body, it is generally sufficient to make measurements from various portions of its surface. The more numerous the portions measured, the more accurate will be the description given by them of the position and shape of the body. It will be readily noticed that by *shape* we mean *relative position of parts.*

21. Observation of Rotation.—It must not be supposed that a knowledge of the exact position of any given portion of a body at two different times is sufficient for the purpose of describing the movement which the body has undergone in the interval, however small this interval may be. We might find that in the interval the separate portions of the body have moved

along paths which do not resemble that of the body as a whole. In other words, a rotation of the body may have taken place in addition to a translation, and it is at once recognisable that the essential of rotation is the possession of parts. That is rotation cannot exist unless a body possesses parts, and it cannot be observed unless we distinguish parts. If a sphere of perfectly even and similarly coloured surface were rotating we should be unaware except by touch. To become aware, marks upon the surface would be needed, from which rough measurements could be made by eyesight. In the case of an irregular-shaped body, rotation is easily observed. By making a hole in a body and placing it on the various wires representing paths, illustrations of rotation may be given and its meaning made clear. Combinations of rotation with the various kinds of translation may also be shown. With this arrangement we find that a given body is capable of ten modes of motion with regard to three given planes, viz., the five which we have shown a point to be capable of exhibiting, together with five others derived from a combination of these with rotary movement. If we are not limited to special planes for purposes of measurement, we are able to arrange all kinds of motion into six classes, namely :—

1. Displacement in a straight line.
2. Displacement in a plane curve.
3. Displacement in a non-planar curve.
4. Displacement in a straight line with rotation, or rotation alone.
5. Displacement in a plane curve with rotation.
6. Displacement in a non-planar curve with rotation.

All these classes should be illustrated not only with single bodies, but with systems of separate bodies, joined together by wires, and so forming a rigid system, that is, a system which does not undergo any internal displacements. In reality the parts of any rigid solid form such a system. If a system undergoes change of shape, if, for example, the wires connecting the various parts of the system used as a model were to shorten or lengthen while other displacements are taking place, it is easy to see how very complicated the path of any member of the system may be.

Additional Exercises and Questions.

1. Why are two lines at least needed in order to define the position of a particle in a given plane?

2. Compare the above method of defining position with that of using angles. Give diagrams.

3. Show by diagrams that the position of one point in a given plane with regard to another requires either two lines at right angles, or two lines drawn from these points to a third, before any description of that position can be given.

4. There are four points in the circumference of a circle which are similarly situated with regard to any two diameters drawn at right angles. How may their position with regard to one another be described?

5. How may the position of a given area be defined?

6. Draw a diagram defining the position of four particles in the same plane with regard to each other, that is, describe the configuration of such a system of particles.

7. Represent, by three sheets of paper or three books, three planes at right angles to one another.

8. Measure on the model planes the distance from each of a small body supported on a wire. Use a piece of string and a scale for measurement. Also measure from the squares by eye.

9. Place several bodies on the model to represent the different positions at different moments of a given body, and bend a wire to show the probable path of the body. What conditions must be assumed before this path can be taken as the true one?

10. Fix wires to show the various paths in which a particle may move with regard to the model.

11. Fix wires which shall represent the possible paths of a portion of a large body. How would they be altered if the shape of the body were changed during the displacement?

12. Show that every portion of a rotating body moves in the second or third mode stated as possible for any particle, that is, either in a plane or non-planar curve.

22. Rate of Change of Position.—When both the extent and duration of a given displacement are observed we become conscious of motion.

The unit of time is the second. If a displacement of a metre along the straight line joining two particles occurs in a second, or of two metres in two seconds, and so on, then if one of the particles be considered as fixed, the other is said to be in motion

at the rate of one metre per second, or to have, if the displacement is uniform, a speed of one metre per second. It is immaterial which body is considered as fixed in position.

The numerical value of the speed of a body so moving is the same as the number of units of length which are added in the unit of time to its distance from a selected origin.

23. Change of Speed, or Acceleration.—Motion is not always constant. It may be variable. If it be constant, the speed of a material particle, measured at two different times, is found to be unchanged. If it be variable, the speed is said to accelerate. The acceleration may be positive or negative, that is, there may be an increase or a decrease of speed. The change in speed occurring in a given interval gives the conception of rate of acceleration, just as speed is derived from combining the magnitude of the distance traversed with the time occupied. It is also obvious that the rate of acceleration may similarly be either constant or variable.

It will be seen that the numerical value of rate of rectilinear and uniform acceleration is measured by the number of units of speed which are gained or lost in a unit of time.

24. Measurement of Time.—We are directly conscious of an order or sequence of events. The experience of all generations has led men to regard certain events as recurring with sufficient regularity to be constituted into fixed points, from which the more variable events may be dated, and by which they may be compared with one another. These regular events are the alternation of day and night, the changes of the moon, and the apparent maximum height of the sun. From these crude reckonings our more exact conceptions have grown; but we still have to depend upon the rotation of the earth for our measure of time.

A chronometer or clock is an instrument constructed so that the index moves over one division of the second-dial in $\frac{1}{86400}$ of the mean solar day. The number of seconds, elapsed since the beginning of the day, is calculated by means of the minute and hour fingers. A chronometer is compared with the revolution of the earth in the following manner :—

A telescope with a vertical cross-wire is mounted so that it swings in the plane of the meridian. The first apparent contact of the sun with the cross-wire is compared with the chronometer, and the contact again noted the next day. This observation gives the length of a solar day. These, however, vary throughout the year. The year is the period in which the earth completes its orbit round the sun. The mean length of all the days throughout the year is found, and it is called the mean solar day. Time-keepers are constructed so that the seconds, marked by them, are $\frac{1}{86400}$ of this calculated mean solar day. This second is the unit in all physical measurements.

The interval between successive transits of the same fixed star is called a sidereal day. A star being practically at an infinite distance, a sidereal day is the accurate period of the earth's rotation. The sidereal day is slightly longer than the mean solar day.

25. The Resultant of Two Simultaneous Displacements.—It is clear that a given displacement may have resulted from a movement along any number and any variety of paths. Observations alone can decide the manner in which the displacement proceeded. A particle may move in a straight line A B, or it may have taken any other path, such as A C, C B (fig. 8). If the particle reach the position B at the same time by either path, a certain relation must hold between the speed along A B and the speeds along the paths A C, C B. The numerical value of the one must be the equivalent of the other two speeds, since the same result is obtained in each case, although the equivalence may not be very clear. If the cause, whatever it may be, which produces the displacement along A C co-exists with the cause which would, if it acted upon the body when it is in the position C, produce the displacement along C B, it will be perceived that the displacement will take place along the path A B, but only in those cases where the directions and amounts of displacement during a given time

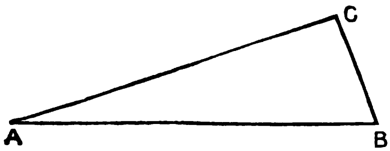


Fig. 8.

could be represented, as in this case, by the three sides of a triangle. In other words, we may have one side of any triangle representing in direction and magnitude the displacement which takes place in a given interval of time, when a body is simultaneously acted upon by two causes which would, if they acted at different but equal intervals, produce displacements represented respectively in magnitude and direction by the other two sides of the triangle. This generalisation may be expressed in still another form. We may say that if a body is subjected to conditions which would bring about a certain speed in a certain direction, and also to further conditions which would bring about, if the previous conditions had not existed, another speed in another direction, then the direction and magnitude of the resultant speed, which the body really acquires under the joint conditions, may be calculated from the rectilinear distance to which the body would have been moved if the component displacements had succeeded one another instead of being simultaneous. In case of two causes, or two combinations of causes, which would be capable in succession of giving to the body the speeds represented by A C and C B happening to coincide in time, then the line A B represents, in magnitude and direction, the resultant speed, or the direction and rate of the resultant displacement. We have therefore to remember, in connection with changes of this kind, not only direction but speed, or rate of displacement.

26. Further Consideration of Simultaneous Displacements. In the last section we have learnt how to find the resultant of two displacements. The method given is applicable to any number of displacements. It is merely necessary to note that our diagrams may be polygons instead of triangles, and that our method only applies to displacements which take place in the same plane. For displacements in different planes diagrams on paper would not suffice, but wire models may be constructed to exhibit both direction and magnitude.

It is easy to see that if a body is acted upon by a cause which is capable of giving a displacement equal and opposite in direction to the resultant of displacements which would be produced by the action of other causes, then the body is at rest

in spite of the several causes tending to move it. It is frequently needed to find the causes which will be effective in keeping the equilibrium of a body in opposition to causes which may tend to displace it in various directions and at various rates. Those conditions will be effective under which the body would acquire a displacement equal and opposite to that which would be the resultant of the other displacements.

It will afterwards be found that these considerations will sometimes be brought to bear upon important problems which require the above processes to be reversed. We frequently require to resolve a given displacement into its components—that is, to ascertain what other displacements would find in this given displacement their own resultant. And most commonly these displacements require to have directions which are at right angles.

The construction of a few diagrams will show that a given displacement may result from an infinite variety of component displacements, and consequently a given displacement may be resolved into an infinite variety of components.

Additional Exercises and Questions.

1. How is it determined whether the velocity of a body is uniform or variable?

2. What is the unit of velocity in the C.G.S. system? What would be the displacement in three minutes of a body moving uniformly with a velocity of seven?

3. Show by a diagram that a single act of displacement may produce the same result as two or more successive displacements.

4. What will be the joint effect of several causes, each of which separately would produce the same displacement in the same direction? What would be the condition of a body acted upon by causes which tend to move it in exactly opposite directions?

5. By what processes would you trace the real path with regard to the earth of a person walking on the deck of a ship in motion (1) forward, (2) aft, (3) from side to side? Draw diagrams and state the data required for calculating his velocity with regard to the earth in each case.

6. What will be the condition of a body which is acted upon at the same moment by causes which would, if they acted in succession, produce in it during equal intervals the displacement represented in direction and magnitude by the three sides of a triangle taken in order?

7. Show that if two adjacent sides of a parallelogram represent in direction and magnitude the displacements produced in equal intervals of time by two given causes, then the diagonal line between them must represent the direction and magnitude of the displacement produced in the same interval of time when these causes act simultaneously.

8. Show that the statements which have been made about displacements which take place in equal intervals of time must necessarily apply to speeds.

9. Show by diagram how to find resultant of any number of displacements occurring simultaneously in the same plane.

10. Construct a wire model to exhibit the resultant of several displacements in different planes.

27. Examples of Mechanical Constraint of Motion.—The ordinary methods of constraining motion or rendering it determinate, and those which may be seen illustrated very frequently in machinery, are three in number, viz., the use of (1) guiding grooves or slots to allow sliding only, (2) pin and eye to allow turning only, (3) helix or screw guides, to allow screwing only. It will be seen that grooves and slots only allow translation in the direction of the groove. The pin and eye allow only rotation about an axis, while the helix allows rotation to proceed simultaneously with translation. It will be seen that the rigidity of solid matter is here utilised to prevent movement except in the desired directions.

These modes of constraint really form the basis of machinery. We may obtain from them examples of all the kinds of displacement of which a body has been shown to be capable. But inasmuch as a body near the surface of the earth has always a tendency to move towards the earth, we always find the other movements of a body modified by this tendency, which also largely influences the structure of machines themselves.

The most common as well as the most effective mode of constraint is that in which a body moves along a straight groove ; examples of this may be seen in a piston working in a cylinder, and guide-blocks working in their guides. A lathe-bed or optical bench will also serve as examples. In these cases it will be seen that all particles of the guided and constrained body have parallel rectilinear paths.

In cases of the second mode of constraint, such as the

movement of a wheel-axle, shafting, or pin on its bearing, all the particles of the constrained body move in concentric paths.

In the third mode of constraint each particle of the body has a helical path, that is, each particle rotates about the same centre, but this centre is itself being displaced in a straight line. That is, the displacement of the whole body is composed of a translation and a rotation. Any hollow screw forms a helical guide.

It is important to note that it makes no difference in any of the above examples which is at rest, the constraining or the constrained body. This follows from what has been previously said about the relativity of motion.

A little consideration will make clear the following statements :—

1. That if one point in a body be fixed, there can only be rotation taking place in that system, but the rotation may take place in any direction.

2. That if two points in a body be fixed, then the given system is still capable of undergoing rotation, but the rotation in question can only take place about the straight line in which these points are found. This straight line is called the axis of rotation.

3. If three points which are not in the same straight line be fixed, then there can be no movement of the body.

4. If one point in a body be constrained to move parallel to a line, the body may undergo rotation or translation or both.

5. If two points in a body be constrained to move parallel to a line, the body may be translated or rotated in one plane.

6. If three points in a body be similarly constrained, the body may only be translated.

28. The Conversion of Circular into Rectilinear Motion. We may readily show that a body may be constrained in two directions at right angles to one another, so as to take a circular path. The rectilinear motion of the bar (fig. 9) between the guides at C and D causes the block E, moving in the groove A B, to have a circular path. The circular motion is produced by two sliding constraints at right angles.

The conversion of circular into rectilinear motion (or, as it is called, reciprocating motion, on account of the to-and-fro

movement in a straight line), and inversely of rectilinear into circular motion, is also seen in fig. 10. A common requirement in mechanism is that rectilinear movement along a given line shall produce circular motion. This is seen in the rectilinear movement of a piston being used to drive a wheel by means of a crank-rod. The model shown may readily be cut out of cardboard and pinned together. The groove C D corresponds with the cylinder, and the part A B acts as a crank-rod, while the circular portion answers to the driving-wheel. By insert-

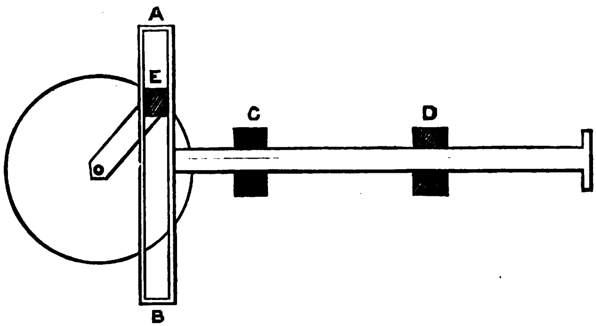


Fig. 9.

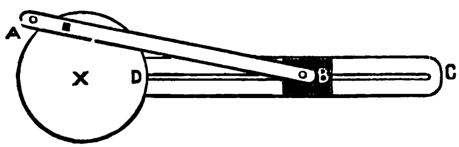


Fig. 10.

ing the point of a pencil through A and B the two paths may be marked on paper.

Methods of mere transference of motion may be seen in the leather bands by means of which motion is handed on from one wheel or pulley to another where needed. In this case we have the rotation of the rim of the pulley causing ordinary rectilinear motion in the band, and this, when it is needed, is again converted by contact with another pulley into rotary motion. In a locomotive the reciprocating motion of

the piston-rod is converted into circular motion in the driving-wheel, and this into the rectilinear movement of the locomotive by the friction of the rails. Every piece of mechanism affords some illustration of change or constraint of motion.

Additional Exercises and Questions.

1. Bend a piece of wire so as to exhibit the path of any particle in a nut moving upon a screw. How would you proceed to make your model exactly represent the path of a certain particle upon a given nut moving on a given screw? Describe also the path of any particle in a screw moving through a stationary nut.

2. Ascertain by direct observation the paths of a particle in a wheel, or round disc, rolling in a straight line. Draw it upon paper, and explain its shape.

3. What would be the path of every portion of a wheel which is spinning and being moved in the direction of its axis?

4. Give examples of each kind of mechanical constraint of motion, stating the mechanisms which exhibit them.

5. How would you fix a given body so that it can move in a circle which may lie in any plane?

6. Suggest a mechanism for converting one rotation into another rotation at right angles.

7. Show by means of a diagram—(1) that when a rigid body is translated, every particle in it moves through an equal distance in the same direction, and (2) that when a rigid body rotates, each particle does not move through the same distance nor in the same direction.

8. Make clear by diagrams and observations that any displacement of a rigid system may be produced by a translation together with a rotation of that system about any point in it.

CHAPTER III

OBSERVATIONS OF CHANGE OF TEMPERATURE

29. Change of Temperature Causes Change of Density.—1. A hot body is placed in contact with a cold one. The cold body becomes warmer and the hot one colder. Generally, when bodies of different temperatures are placed together they will be found to assume the same temperature gradually.

2. Observe the increase in size of a piece of iron, or better, of platinum, when in contact with a hotter body, for example, a gas flame. Counterpoise when cold, and after it has been in contact with the hot body, replace it on the balance. Observe that the balance does not indicate any change in the quantity of matter. Generally, a rise in temperature is accompanied by a decrease in density, *i.e.*, the same quantity of matter fills a larger volume.

3. Fill a small flask with water, mark on the flask the level of the water, and fill a similar flask with the same volume of mercury, and mark its level likewise. Place the flasks in contact with a warmer body, *e.g.*, place them within a vessel containing hot water heated by a gas flame. Observe that the level of each liquid changes, but to a different extent; while the quantity of matter in each case may be shown, by the balance, to be unchanged. Both the mercury and the water are raised to the same temperature; but their densities are not equally diminished. The glass of the flasks will also change in density, but to the same extent for each, so that the apparent expansions give the actual relative expansions.

The thermal condition or temperature of a body changes by thermal conduction or radiation. Conduction is dependent on material contact, that is, it only takes place when bodies

touch one another, but radiation takes place between bodies when separated even by great distances. In any system of material bodies, whatever may be their natures, relative positions, and temperatures, the final condition of the system is one in which they are all at the same temperature. The change may proceed by conduction or radiation, or by both. It is to be noted that we are directly conscious of variety of temperature, just as we are directly conscious of variety of motion.

30. Standard Temperatures.—1. Observe that a thermometer shows the temperature of ice to remain constant while melting. Several observations are to be made. The density of the mercury in a thermometer does not alter until all the ice is melted.

2. Observe similarly that the temperature of water, when it boils under unaltered conditions, remains constant.

3. Note that these two statements cease to be true if the thermometer is very large compared with the quantity of ice or water used. In each case the introduction of the thermometer, a body of a different temperature, affects the thermal condition of the system; but after a time the thermal condition becomes constant again, and is unaltered so long as the water boils or the ice is melting.

Two standard temperatures are thus found, and other temperatures may be compared with them. The ordinary thermometer is constructed of a thin closed glass tube with a bulb at one end. This bulb, and a portion of the narrow even bore of the tube, contains pure mercury. The rest of the tube is empty, so as to allow free movement of the mercury. We perceive that an alteration of temperature causes the mercury to expand more than the glass containing it. The use of the instrument is founded on this inequality of expansion.

The variations in the level of the mercury column, due to changes of density, are observed by the help of a scale. This scale is constructed by marking as zero the position of the column when the thermometer is placed in melting ice; and, when the thermometer is in boiling water, marking the position of the column 100°. Between these points the scale is

subdivided into 100 equal lengths. A thermometer with a scale of this kind is said to be centigrade.

When a portion of matter is at such a temperature that the mercury in a thermometer, placed so as to be in thermal equilibrium with it, stands opposite a certain number on the scale, that portion of matter is said to have a temperature of that number of degrees. For example, if the level of the mercury is at 15 the body is said to have a temperature of 15 degrees centigrade (or 15° C.). There is no difficulty in perceiving that we add nothing, so far, to our knowledge, when we say that a body is at 15° C. temperature. The thermometer is an instrument which enables us to say when two bodies are in the same thermal condition, on the assumption that similar causes produce similar effects. This assumption will afterwards be found to be reasonable. We cannot, however, yet consider that these numbers or degrees afford anything more than a rough comparison of different thermal conditions, nor is it likely that they give any correct information about the real basis of temperature.

By the use of the balance we are able to decide when two quantities of matter are equal, and by the use of the thermometer we can judge when two bodies are at the same temperature. But by the use of the balance we can compare two quantities of matter, by collecting together a sufficient number of sufficiently small standard quantities to produce in each case the same effect. The numbers then indicate the relation in quantity. In the case of temperature, on the other hand, we have at present no means of estimating quantity, and we are face to face with a different order of phenomena. Equality of temperature, just like sameness of colour, has no apparent connection with quantity. We begin now to deal with a condition or quality which cannot be isolated from matter, and which cannot be divided into parts or added together. We can, however, observe that *changes* of temperature are determined both by the quantity and the kind of matter in which they take place. By combining the conception of temperature with that of matter we may regard a change of temperature as a measurable quantity.

31. Relation of Temperature-changes to Quality and Quantity of Matter.—1. Observe that when two quantities of water at different temperatures are mixed, the resultant temperature of the mixture is intermediate and varies with the quantity and temperature of each.

2. Observe that when equal quantities of turpentine and water at the same temperature are mixed respectively with equal quantities of water at a different temperature, the mixtures do not agree in temperature.

3. Observe that if two quantities of water at the same temperature, one of which is double the other, be mixed respectively with two other quantities of water, also in the ratio of 2 to 1, but at a different temperature, then the same temperature results in each case. Observe also that this holds true for other liquids, *e.g.* turpentine, and for other relative quantities, *e.g.* 3 to 1, or 2 to 3, and so on.

The above exercises show that, when bodies of different temperatures are brought together, the resultant temperature varies with the quantity and nature of the matter contained by these bodies. The same temperature, however, is obtained if two quantities of matter, one at a high and one at a low temperature, be mixed, as is obtained when we mix two different quantities, at the same respective temperatures, either of the same or a different kind of matter, provided only the same relation in quantity be maintained. It is almost unnecessary to state that this experiment, and all others too, will be accurate only when our observation includes everything that is changed during the operation. Any change of temperature in one body proceeds simultaneously with changes of some kind in one or more other bodies. We are now concerned, however, with co-existent thermal changes only, and these may be observed to be reciprocal, *i.e.* a certain quantity of matter rises in temperature while another quantity falls. If a hot body be exposed in a room, the temperature of the surrounding bodies, including that of the air and the walls of the room, will rise, whilst its own temperature falls, until there is the same temperature everywhere. Hence arises the necessity in these preliminary observations of using liquids

which mix together so completely that they readily come to the same temperature throughout. The errors, due to changes in other bodies, must, however, always be taken into account.

Various methods of raising different kinds of matter to the same temperature are possible. It is convenient to place them in thin glass vessels inside a larger vessel of hot or boiling water until a thermometer indicates the same temperature.

32. Equal Quantities of Ice Melted during Equal Temperature-changes in Equal Quantities of the same Kind of Matter.—1. Place equal quantities of ice in equal quantities of water at the same temperature, and observe in each case that the water is at the same, though lower, temperature, after the ice is melted.

2. Observe that the quantity of ice melted in an ice calorimeter varies directly with the quantity of matter used, provided the bodies inserted are of the same temperature and of the same kind of matter.

3. Observe that equal quantities of different kinds of matter at the same temperature melt different quantities of ice, although they have meanwhile undergone the same changes of temperature. Use mercury and water.

The above exercises show that the same physical change—that is, the change of a given quantity of ice to water—is accompanied by an external change of temperature, which varies in different kinds of matter, but bears a simple relation to the quantity of matter undergoing it. The same change, of temperature in equal quantities of the same kind of matter is accompanied by equal changes, whether of temperature or of another class, in equal quantities of other bodies, but the same temperature-changes in equal quantities of different kinds of matter are not equivalent. They are not reciprocal with equal changes in other bodies.

The change from ice to water is not a change of temperature. The temperature remains the same, although neighbouring bodies simultaneously undergo a considerable thermal change which may be shown to be, for the same quantity of ice, constant in magnitude.

One form of an ice-calorimeter consists of several vessels with ice arranged so that a hot body placed inside may cause some of the ice to be melted and allow it to be measured. With the construction shown in fig. 11, the quantity of water which runs out into A measures the amount of ice melted by the body placed in B. The ice-jacket C C prevents the ice in D being melted by an external change of temperature.

A calorimeter yielding more accurate results is one in which the quantity of ice melted is measured by the diminution of

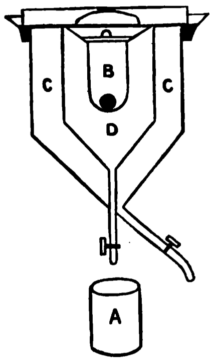


Fig. 11.

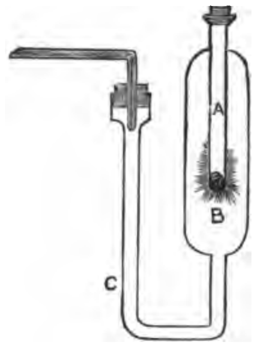


Fig. 12.

volume then taking place. Water in B (fig. 12) is caused to freeze around the tube A by a cold body placed within it. The tube C is connected with a mercury gauge which indicates changes of volume, and the body to be investigated is dropped into A. This instrument requires more care in manipulation than the former, especially in fixing on the gauge. The experiment need not be performed at this stage.

33. To Measure the Corresponding Temperature-changes in Water and Copper.—Weigh about 20 grams of copper wire rolled into a ball; attach a thread of silk, place it in a large test tube together with a thermometer, and then immerse both for five minutes in boiling water. The thermometer will indicate the exact temperature. At the same time have ready a known quantity of water in a glass beaker, with a

thermometer showing its temperature. Convey the copper to the beaker as quickly as possible by means of the silk, and note the change of temperature taking place.

The temperature of the known quantity of water rises, whilst that of the known quantity of copper falls, until there is thermal equilibrium ; but the resultant temperature shows that the fall is not equal to the rise, nor are the respective changes proportional to the relative quantities of copper and water present.

Although it leads to greater accuracy to use a relatively large quantity of water in this experiment, we may infer that with equal quantities of water and copper different temperature-changes would be reciprocal. Observations with other substances indicate, similarly, that the same temperature changes (as marked by the thermometer) are not equivalent for different kinds of matter. It must be remembered that only approximate results will be obtained unless we prevent surrounding bodies, including the air, from taking part in the thermal changes without being estimated in our calculations. Calorimeters, such as already described, are intended to effect this requirement.

A unit of temperature-change is required for purposes of measurement. Pure water at any temperature between 0° and 4° is selected as the standard substance in which it is to be observed.

A change of 1° C. in 1 gram of water at any temperature between 0° and 4° C. constitutes the unit temperature-change, and forms a basis for thermal measurements. If 2 grams of water are thus altered there are 2 units of temperature-change, and if 2 grams alter by 2°, as indicated by the thermometer, the numerical value of the total temperature-change is 4.

Accurate observation shows that very nearly the same numerical values are obtained if the temperature-changes, which commence on a higher point of the scale, are taken as equal to similar changes between 0° and 4° C. In rough experiments this may always be done. A change from 20° to 21° may be considered equal to a change from 2° to 3°.

A given substance may be conveniently raised to a high temperature, and transferred to the known quantity of water with less risk of its temperature falling during the transfer, if, instead of the last process, we use a wide tube A (fig. 13), fitted at each end with a cork, through which an inner tube B passes.

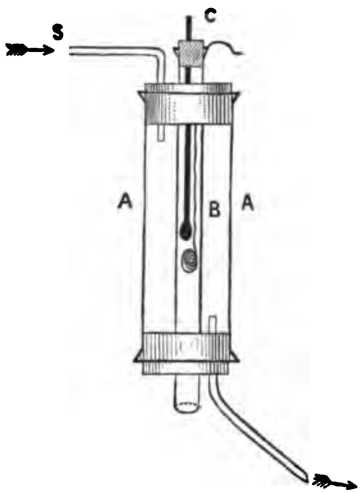


Fig. 13.

The space between the two tubes is now filled with steam by connecting it at S with a flask of boiling water; a cork, into which a thermometer C is fitted, serves to hold the body suspended in the inner tube, and to allow it to fall, when required, into the water, which should be placed directly underneath.

We learn from the table below that a given change of temperature in 1 gram of water is equivalent to the same change of temperature in 1·62 grams of ethyl alcohol, 2·22 of benzene, 10·64 of brass, and so on. These values will be found to bear no relation to densities or to the quantities of matter in equal volumes of the various bodies. They indicate a totally distinct relationship between various kinds of matter, and later observations in electricity and chemistry will show that this relationship may be discovered in other phenomena.

Thermal Equivalents.

Numbers expressing the Relative Quantities of Various Kinds of Matter which are Equivalent in Thermal Change. Water is taken as Unity. So-called 'Specific Heats' are the Reciprocals of these Numbers.

Air	4214·7	Ice	2·00
Aluminium	4·950	Iron	8·92
Antimony	18·343	Lead	31·74
Arsenic	12·285	Magnesium	4·081
Bismuth	32·786	Mercury (liquid)	31·328
Brass	10·64	Platinum	30·864
Benzene	2·22	Silver	17·889
Cadmium	10·649	Sodium	3·408
Copper	10·52	Sulphur	5·43
Ethyl alcohol	1·62	Tin	17·889
Glass	5·05	Water	1·00
Gold	30·864	Zinc	10·69
Hydrogen sulphate	3·33		

We may, perhaps, now begin to regard thermal changes as conditional, not on the volumes nor the masses of the bodies taking part in them, but rather on something which is within the body itself. Equal masses are not equivalent, nor are equal volumes. Further investigation will show that under certain conditions the minute particles which are supposed to constitute matter are thermally equivalent.

34. To Measure the Numerical Value of the Temperature-change occurring in Surrounding Bodies when 1 gram of Ice Liquefies.—A weighed quantity of water in a glass beaker is prepared, and its temperature ascertained by a thermometer. Ice which has been standing in the room for some time, so as not to have a lower temperature than 0° C., and which has been dried, is added in quantity afterwards determined by re-weighing the beaker and water. When all the ice is melted, and the whole has been thoroughly stirred with the thermometer, the temperature is again noted.

A known quantity of ice has changed to water without change of temperature (remaining at 0° C.), and has then

altered from 0° C. to the observed temperature of the mixture. These two changes have proceeded simultaneously with the temperature-change in the quantity of water first taken, which has fallen from its original temperature to that of the mixture. By making use of the definition of the unit temperature-change we can obtain a numerical value for the latter temperature-change, and likewise one for the water yielded by the ice in rising from 0° to the final temperature. The difference between the two magnitudes gives the numerical value corresponding with the change of state of the quantity of ice which has been used; and from this it is easy to calculate the numerical value for 1 gram of ice.

The most accurate values obtained have been from 79 to 80, but this experiment will only give approximate results, since the changes produced in the air and the beaker itself have not been taken into account. Greater accuracy may, however, be obtained by enclosing the beaker in non-conducting material, such as cotton-wool, and finding out how much water the glass of the beaker would be equivalent to, and adding this to the other quantity thermally changed.

We must infer that the melting of ice is always accompanied by changes equivalent to those here measured, whatever the surrounding bodies may be.

It is convenient in thermal measurement to consider the unit change of temperature as caused by a unit quantity of heat. We may then shortly describe the above process by saying that 80 units of heat are required to melt 1 gram of ice. If the temperature of a body rises, it is said to gain heat; if it falls, to lose it. But as we are able to observe directly only such changes in the properties of bodies as we have agreed to class together as temperature-changes, or as caused by temperature-changes, it is important to remember that the terms, gain, or loss of 'heat,' are merely convenient expressions for changes of temperature. More exact knowledge of temperature-change cannot be acquired until its corelation with other physical changes is shown. We shall then learn what it is that is gained or lost during change of temperature, and why it is that the passage of ice, and of all

other solids, to the liquid state involves a thermal change in surrounding bodies without any change in their own temperature.

35. To Measure the Temperature-change in a Known Quantity of Water corresponding with the Gasification of a Known Quantity of Water, or the Numerical Value of the Temperature-change involved in changing 1 gram of Water at 100° into Steam at 100°.—A known quantity of water is taken in a glass beaker, its temperature is ascertained, and then steam or water-gas is allowed to pass into it for a short time. The quantity of steam added and the change of temperature produced is easily determined, but it is important that only water gas and not condensed steam be added, or the determinations will be inaccurate. With this purpose the tube A, leading the steam into the water, is a narrow tube, fitted with a cork into the bigger tube B, so that the steam leading into the water is maintained at 100°, and is shielded from the cooler air by the steam in B, which will be found to condense partly. The water in the beaker C should be shielded from the effects of the flame by which the water in the flask D is made to boil.

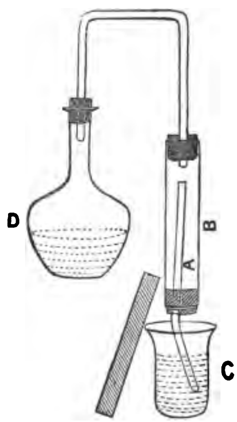


Fig. 14.

This method is not direct, and we have to assume that the change is reversible. That is, the gasification of a given quantity is accompanied by the same temperature-change as when it is condensed, except that the direction of the change is reversed. In the first case the temperature would be lowered (as it was in the melting of ice), in the latter it is raised. The truth of this is proved by many observations.

As in the case of the liquefaction of ice, there are two operations together balancing a third. The rise in temperature of the known quantity of water co-exists with the condensation of a known quantity of steam, together with the

fall in temperature of the water formed from the steam, which must change from 100° to the final temperature of the mixture. Thence the numerical value of the temperature-change, corresponding with the condensation of a certain quantity of steam, is obtained by subtracting, from the total numerical value of the temperature-change in the water, the numerical value obtained from the condensed steam falling from 100° to the final temperature. The value for 1 gram is then calculated.

The most accurate observations have shown the numerical value for 1 gram of water at 100° converted into steam at 100° to be 536. This number 536 has, unfortunately, been called the latent heat of steam ; and the number 80, the latent heat of water. Corresponding changes occur when any liquid passes to the state of gas.

Table showing the Number of Grams of Water which would be changed from 1° *to* 0° *C. by the Fusion of* 1 *gram of the following Solids* :—

Beeswax	97·22
Lead	5·37
Ice	79·25
Sulphur	9·35
Spermaceti	82·22
Silver	21·07
Tin	14·25
Zinc	28·13

and by the Vaporisation of the following Liquids :—

Bromine	45·6
Ethyl alcohol	209
Ethyl ether	91
Mercury	62
Sulphur (liquid)	362
Turpentine	69
Water	536

The above numbers are also called the 'latent heats' of fusion and vaporisation.

Temperatures at which some Solids Melt under Normal Pressure of the Atmosphere.

Aluminium	600° C. about
Antimony	440° C.
Arsenic	210° C.
Brass	1,015° C. about
Copper	1,050° C. about
Gold	1,250° C. about
Ice	0° C.
Iron	1,600° C. about
Lead	335° C.
Mercury	−39·5° C.
Platinum	1,700° C. about
Silver	1,000° C. about
Sodium	95·6° C. about
Sulphur	114·5° C.
Tin	235° C.
Zinc	450° C.

Temperatures at which some Liquids Boil under Normal Pressure.

Amyl alcohol	131·8° C.	Glycerine	290° C.
Ethyl alcohol	78·3° C.	Hydrogen acetate	120° C.
Benzene	80·8° C.	Hydrogen nitrate	86° C.
Bromine	63·0° C.	Hydrogen sulphate	326° C.
Carbon disulphide	48·0° C.	Mercury	350° C.
Ethyl ether	35·5° C.	Turpentine	156° C.

Density and Volume of Mercury at Various Temperatures.

Temperature, ° C.	Density	Relative Volume
0	13·596	1·000000
4	13·586	1·000716
5	13·584	1·000896
10	13·572	1·001792
15	13·559	1·002691
20	13·547	1·003590
30	13·523	1·005393
40	13·499	1·007201
50	13·474	1·009013
60	13·450	1·010831
70	13·426	1·012655
80	13·401	1·014482
90	13·377	1·016315
100	13·353	1·018153

Density and Volume of Water at Various Temperatures.

Temperature ° C.	Density	Relative Volume
0	·999884	1·000129
1	·999941	1·000072
2	·999982	1·000031
3	1·000004	1·000009
4	1·000013	1·000000
5	1·000003	1·000010
6	·999983	1·000030
7	·999946	1·000067
8	·999899	1·000114
9	·999837	1·000176
10	·999760	1.000253
11	·999668	1·000345
12	·999562	1·000451
13	·999443	1·000570
14	·999312	1·000701
15	·999173	1·000841
16	·999015	1·000999
17	·998854	1·001160
18	·998667	1·001348
19	·998473	1·001542
20	·998272	1·001744
21	·998060	1·001957
22	·997839	1·002177
23	·997614	1·002405
24	·997380	1·002641
25	·997133	1·002888
26	·996879	1·003144
27	·996616	1·003408
28	·996344	1·003682
29	·996064	1·003965
30	·995778	1·004253
40	·99236	1·00770
50	·98821	1·01195
60	·98339	1·01691
70	·97795	1·02256
80	·97195	1·02887
90	·96557	1·03567
100	·95866	1·04312

Mean Increase of Unit Volume for Rise of 1° *C. in Temperature, or Mean Coefficient of Cubical Expansion.*

Alcohol (ethyl) . .	·00108
Brass	·0000172
Copper	·00005
Glass	·000023

Gold	·00004411
Hydrogen sulphate .	·000489
Ice	·0001585
Iron . . .	·0000355
Lead	·000084
Platinum	·000026
Mercury	·00018
Silver	·0000583
Tin	·000069
Zinc	·000089

The coefficient of linear expansion, or the increase in unit length, is approximately one-third the cubical coefficient.

Additional Exercises and Questions.

1. Show that we make use of the same reasons in determining that two temperatures are alike as in determining that two quantities of matter are alike. But show also that we cannot compare two temperatures as we compare two quantities of matter.

2. Compare the results given by a thermometer with your own sensations when various objects, metallic and otherwise, are touched. What explanation can be given of the apparent discrepancy? Ascertain the temperature of your own body before offering an explanation.

3. Give the precise meaning to be attached to the terms 'heat' and 'temperature.' In what way may 'heat' be looked upon as a quantity?

4. Classify the chief changes which may proceed simultaneously with changes of temperature in a body.

5. Observe the effect of raising the temperature of a tightly stretched wire. Suggest other methods of showing expansion and contraction with change of temperature.

6. Find the length of a brass and of an iron rod, first when they are placed in ice, and, secondly, after immersion in hot water of which the temperature is taken. Calculate from your observations the fraction of the length at zero by which each has increased during the observed change of temperature, and also the average increase for a change of 1°. The decimal fraction obtained from the latter calculation is called the coefficient of linear expansion. Measure by an eyepiece, connected with a vernier, travelling along a graduated bar.

7. Fit corks carrying glass tubes into flasks of equal capacity filled with water, turpentine, and mercury, so that no air remains in the flask and the liquids rise within the tubes to a convenient level. Rule lines at a distance of half a centimetre on strips of paper and gum them to

the tubes; then place the flasks within a large vessel containing water, and observe the alterations of each level while the temperature of the water in the large vessel is being continuously raised by a flame. Keep a record of the heights at different temperatures, and trace curves which exhibit the relative changes of level. Observe also very carefully the changes of level taking place as the liquids are cooled by being surrounded by ice instead of water.

8. Heat the end of a glass rod until it is soft, and then push into it a piece of platinum wire. (Lengths suitable for subsequent use in the chemical laboratory should be used.) Observe that the platinum is tightly fixed after cooling, and give the reason.

9. Show from the relation existing between the volume of a cube and its linear dimensions that the coefficient of voluminal expansion is slightly more than three times the linear coefficient, provided the expansion is equal in all directions.

10. Observe the different lengths of time occupied in bringing about thermal equilibrium in the case of different kinds of matter. Coat rods of glass, iron, and copper with paraffin, pass them through a cork to the same distance, and fix the cork in a flask of boiling water.

11. Why is thin glass less likely than thick glass to crack from a rapid change of temperature?

12. Knowing that most gases increase by about ·00366 of their volume for an increase of 1° C., what is the density of air at 15° C. if it is ·0012932 at 0° C.?

13. Observe the melting-point of paraffin and beeswax by placing a small quantity of each in separate small tubes, fastening them to the bottom of a thermometer, and immersing them in a beaker of water which is gradually raised in temperature by a small flame. The water should be heated slowly and constantly stirred.

14. Suggest a method of showing change of temperature by the expansion of air. How would you compare the readings of your instrument with those of an ordinary thermometer?

15. Temperature might be ascertained by means of a vessel constructed so that a liquid inside it would have to leave the vessel if it expanded. From the relation between the quantities remaining and the original quantity the voluminal expansion may be calculated, and hence the temperature may be determined, if the rate of expansion for the liquid is known, and if the starting temperature is known. Describe an instrument of this kind and the use to which it can be put.

16. Give descriptions of possible calorimeters, and mention the advantages and disadvantages of each.

17. The observed alteration of volume in a liquid contained in a vessel is not the real change, for the capacity of the vessel itself is simultaneously undergoing change. How may the absolute expansion

of a liquid be found if the coefficient of voluminal expansion for glass is known?

18. Describe how the absolute expansion of a liquid may be found by weighing a piece of glass immersed in the liquid at different temperatures. What are the probable inaccuracies of the method?

19. Mention the advantages and disadvantages of Lavoisier's calorimeter. Mention how some of the inaccuracies may be made relatively small.

20. How could you demonstrate that changes of temperature are changes which relate to quantity of matter and not to volume? What hypothesis can you suggest as to the real process which underlies what we call change of temperature?

CHAPTER IV

OBSERVATIONS OF CERTAIN MUTUAL CHANGES COMMON TO ALL KINDS OF MATTER

36. Bodies displaced Equally from the Surface of the Earth reach it again Simultaneously if allowed to Fall.—A large electro-magnet may be used for suspending two bodies at the same height. When the current is disconnected the bodies fall at the same rate. One body may be of iron, the other of wood with a piece of iron fixed so that the magnet will hold it. A piece of paper between the ends of the electro-magnet and the bodies ensures their simultaneous detachment. Variation, either in the quantity or kind of matter, does not change the result. All bodies let fall at the same instant and from the same height reach the earth at the same time, except so far as the obstruction of the air may intervene. Bodies which vary in falling in the air are found to be alike when tried *in vacuo.* If the displacement is varied the statement will be found to hold good.

In this observation we have assumed the earth to remain at rest, while the two small bodies are said to be moving. By making this assumption, which our definition of movement justifies, we simplify all such investigations. The system under observation contains the earth and these two bodies. No change in the surroundings, however varied or repeated, has ever been found to annul either the power of return of any given body when removed from the earth, or the equal rate of return of two bodies equally removed. It is clear, then, that the earth and such bodies are alone concerned in this special change, and they constitute a material system in which

any vertical displacement is followed by a return to the original relative positions.

37. The Manner in which a Displaced Body returns to the Earth.—The Time of Fall.—A body allowed to fall from a height of 16 feet reaches the ground in one second.

A body allowed to fall from a height of 64 feet reaches the ground in two seconds. In the last second it must therefore fall through 48 feet, if it takes, as may be proved, the first second in falling through 16 feet.[1]

The first fact may be demonstrated by suspending the body by an electro-magnet. Then break the current, and thus remove the support, at one tick of the seconds-pendulum. The body will reach the ground at the next tick.

The second fact is not always easy to demonstrate on account of the distance being inconveniently great, but it may be accepted as the result of many experiments.

More accurate measurements show that, if the resistance of the air be allowed for, the fall in a second is 490·5 centimetres, and in two seconds 1,962 centimetres.

The result of all observations of the fall of bodies to the earth is to show that the rate of fall gradually increases along the course, and that the longer the course—or, in other words, the greater the original displacement—the greater the speed with which they reach the earth.

38. When a Body is displaced from the Surface of the Earth and then set free, it returns with a Uniformly Accelerated Speed in a Straight Line.—That a body, displaced a short distance from the surface of the earth and allowed to fall, returns in a straight line, is a matter of direct observation.

That it returns with a uniformly accelerated speed is inconvenient to prove directly, on account of the magnitude being too great to measure in a room. The law may, however, be proved by retarding the motion and then measuring. This is best arranged by using Atwood's machine in conjunction with a pendulum beating seconds, or a clock.

[1] It would not necessarily follow that it took one second to fall through 16 feet at the greater distance from the earth, but experiment shows that this is true within a moderate range.

Two equal masses are connected by a silk thread which passes over a pulley turning on friction-wheels. A small additional mass is made to rest on the mass near the scale. This causes an acceleration to be given to the masses, the heavier descending. By trial, the space passed over in one second may be noted, and the moveable stage placed there. Then the commencement and end of the fall will agree with two consecutive ticks of the seconds-clock. The space passed over during two seconds will be found to be four times that passed over during one second, and during three seconds, nine times, and so on. In order to give a long drop the pulley should be fixed as high as possible.

These observed phenomena, together with those of the last section, may be most simply explained on the supposition that the acceleration which a body acquires by its proximity to the earth is independent of any motion which it may already have. A body, displaced 16 feet from the earth and allowed to fall, has at the moment it is stopped, *i.e.* at the end of one second, a speed of 32 feet per second, but if it has had a displacement of 64 feet, it will take two seconds to return, and will, at the end of the first second, have a speed of 32 feet per second, with which it commences the last second. Consequently it has at the end of two seconds a speed of 32 *plus* 32, *i.e.* 64, and at the end of t seconds a velocity of $32t$. In using Atwood's machine, the displacement of a body from the earth's surface corresponds with the distance between the starting-point and the stage which checks the fall.

We may here state Newton's First Law of Motion, which is bound up with the above explanation :—'Every body perseveres in its state of rest or of moving uniformly in a straight line, except so far as it is made to change that state by external force.'

39. Meaning of the Term 'Force.'—When a body falls to the earth there is a change in the material system comprising the earth and that body. Each must be considered essential to the change—that is, it is a mutual change.

The inevitableness of the return of a body to the earth gives rise to the statement that it is caused by the attraction

of the earth, or gravitation, but it is more exact to say that a mutual action, or a stress, exists between the two. The phrase *attraction of the earth* fails to convey the mutual nature of the change.

We have seen that displacement between two bodies can only be measured by considering one of them to be at rest. So also mutual action is generally measured by its effect on one body.

We may say that the earth moves to the displaced body, and consider the displaced body to remain fixed after it is released; or we may consider the earth to be fixed, and the body to move. We have no reason, so far, for taking one aspect of the change in preference to the other. We shall learn later that, relatively to any body not taking part in the mutual change, the earth must be considered to move, although to an infinitesimal degree, at the same time as the other body undergoes its much more apparent change. The displacements are, in fact, inversely proportional to the masses.

Taking the customary and convenient conception of force, it may be defined as—whatever changes or tends to change the motion of a body by altering either its direction or its magnitude. But since observations show that change of motion in one body is always accompanied by change of motion, or change of some other kind, in another body, we must not forget that in using the term or idea, 'force,' we confine our attention to one side only of a two-sided event. This two-sided event is the mutual change that always occurs wherever stress manifests itself.

It is to be noted in the case of the mutual action here investigated that the motion takes place in the straight line joining the centres of the bodies—in other words, the body moves towards the centre of the earth.

40. The Moveable Pulley.—A cord is fixed at one end, then passes over the moveable pulley A, and next over the fixed pulley B. The free end of the cord C and the pulley A are each furnished with a hook. If a known mass is attached to the free end of the cord it may be made to raise a mass nearly double its own in quantity. We must take into

account the mass of the pulley, which is raised together with the attached mass.

The more completely friction is avoided, the more nearly will a given total mass at A be balanced by one-half its mass at C, and the smaller will be the excess over one-half which is needed to cause the fall of C and the rise of A.

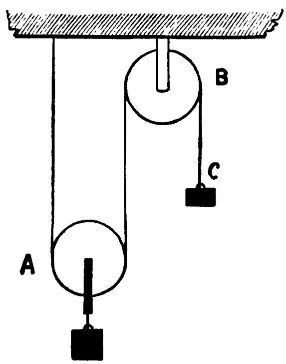


Fig. 15.

While there is no movement, we have a system in equilibrium; the stress between the earth and C balances the stress between the earth and A by the aid of the cord.

It is easy to see that in such an arrangement, where the three portions of the cord are all parallel, the mass at C would descend through twice the distance ascended by the mass at A.

With a combination of pulleys, which consists of two blocks, each with three pulleys, and a continuous cord passing over each pulley, it is easy to see that the ascending mass would move through one-eighth the distance of the descent made by the smaller mass; and, if it were not for the effect of friction, which is much greater in such a system, a given mass would balance one eight times larger.

These experiments illustrate the need of considering both mass and distance in all such mutual changes.

41. The Lever.—The lever, like the pulley, shows that both mass and distance must be considered in all cases of mutual change. Its principle is illustrated by a rigid rod supported on an edge or small surface, called the fulcrum. If this rod is of constant section and homogeneous material it will be found to balance when supported at the centre, the stress on the one side of the fulcrum being just equal to that on the other. In any displacement from the horizontal position each particle on one side of the fulcrum has a corresponding

particle on the other side, undergoing a displacement exactly equal, but opposite, to its own.

If, however, the position of the fulcrum is altered, there is no longer equilibrium between the two opposing stresses, and the heavier side descends. This may be prevented by attaching a mass or restraint to the other side. Varying masses may be attached at varying distances and their effectiveness determined. By using a spring balance or dynamometer at different positions the same results may be made apparent.

If the mass of the rod be very small in comparison with the adjustable masses kept in equilibrium by its agency, we may pay attention to these masses alone. We shall then find that, in cases of equilibrium, the vertical distances through which each mass moves, if the rod is displaced, are inversely proportional to the masses themselves. This may be shown by fixing to each mass a pencil, so that their displacement may be marked on two sheets of paper placed in position behind the lever. From these and similar observations it is known that the lever will be in equilibrium if the sum of the products of the numerical values of the vertical displacements and of the masses for all the particles of matter on the one side of the fulcrum be equal to the sum of the same products for every particle on the other side the fulcrum. If any considerable displacement occurs some of the matter on one side may change to the other side, and equilibrium be destroyed.

The beam of a good balance will be found to exhibit all the properties of a lever balanced at its centre on the smallest area which is practicable. Hence if the pans and the masses in them are together equal the lever is in equilibrium.

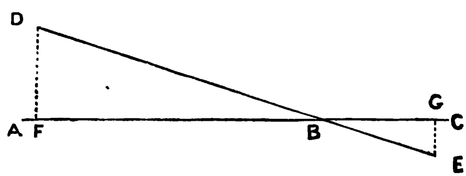


Fig. 16.

It may be shown by geometry that the vertical displacement will always be proportional to the horizontal distance from the fulcrum—that is, DF : GE :: BD : BE. (See fig 16.)

The practical requirements for observations with the lever are as follows:—A wooden rod about 4 square centimetres section and about $1\frac{1}{2}$ metre long; a wooden edge placed so as to act as fulcrum; a pulley fixed so that the rod may be balanced if necessary by means of a cord passing over it. At the ends of the cord are fixed two hooks, one to receive the rod at its centre, and the other to hold a body just able to counterpoise the rod. In this way we get rid of the difficulty of calculating for the mass of the rod, and may pay attention solely to various masses which may be hung from the rod at various positions, while at the same time the position of the fulcrum may be altered.

42. The Pressure of Liquids.—When a liquid is at rest its free surface is horizontal, except where it is in near contact with a solid; and this is true however much the surface may be modified by the shape of the containing vessel. In other words, all portions of the free surface of any homogeneous liquid at rest are in the same horizontal plane. But when we speak of a free surface we mean that portion of the liquid which is in contact with the atmosphere.

The first and second of the figures below show a liquid with two equal free surfaces (A and B), each in contact with the atmosphere, and in the same plane. The third shows that they are still in the same plane when they are unequal. In the fourth case, the closed space B C must contain air, or other gas, in the same condition as the air outside the tube, or, as we have seen, the two surfaces A and B would not be in the same plane. In the fifth case the air has been driven out of the tube, while mercury has been poured in, and the space C D is a vacuum. We must conclude, in this case, that the column of mercury B C has the same effect on the imaginary surface B as the atmosphere would have had, if the surface had been exposed to it as in No. 1. In other words, the atmosphere at the surface A, and the column of mercury above B, are in equilibrium.

Further investigation of these facts must be postponed until more is learnt of the structure of matter. We shall require help from the theory that matter is discontinuous

before we can gain clearer conceptions, either of the manner in which a gas can resist a liquid, as at A in No. 5, or of the nature of the equilibrium in such a case as No. 3.

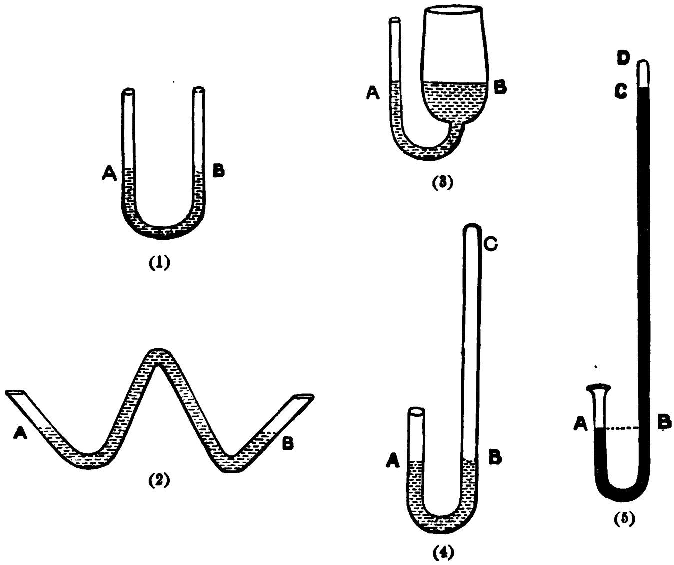


Fig. 17.

43. The Equilibrium of Two Liquid Columns in Communication.—When a liquid—water, for example—is at rest in a bent tube of even bore of the shape A (fig. 18), the two surfaces are at the same level, and we may consider any two portions of the vertical columns which are equal in vertical height, as *a b* and *c d*, to balance one another—that is, the stresses between these two equal quantities of matter and the earth are equal.

If, however, the tube is of the shape B (fig. 18), the surfaces are similarly level, although equally long columns, *a b* and *c d*, do not contain equal quantities of matter. It is necessary to understand why two such columns are in equilibrium

We may be helped to do so by observing the result of adding to one of the columns a known quantity of water.

Cork one of the branches tightly, and fill it with water by inverting the vessel. Add or remove water till the level stands a short way up the other branch. Then add successive equal quantities of water, say 5 c.c., from a burette, and mark each level upon a strip of paper gummed along the branch, or else mark the glass with a diamond. Calibrate the other branch similarly, starting, for convenience, at the same level. The distance between each mark in each branch may now be divided into five equal parts, and the columns will be calibrated in cubic centimetres with sufficient accuracy.

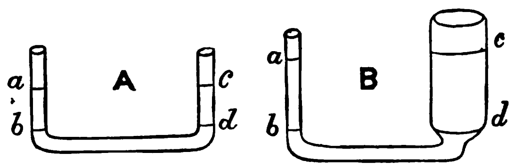


Fig. 18.

Water is now added to this calibrated vessel, and the level in each limb noted. Five cubic centimetres of water are now dropped from the burette into the narrow branch, and the levels again noted. Had there been no movement of the liquid, the addition of 5 c.c. of water would have raised the level through a vertical distance which is easily measured from the graduated marks by a scale. But this level has now changed through a measurable distance and we may say that 5 c.c. of water have moved through this distance, while the change of level in the other limb enables us to calculate what quantity of water has been simultaneously raised through a measurable distance.

It should be found that the quantities of water are inversely proportional to the distance through which they have been displaced, and we have the same kind of change as in the lever, illustrated under somewhat analogous conditions. In this calculation we assume that there is no alteration of

volume in the liquid during the experiment. With the conditions described there is no alteration, as the measurement of the total volume would show. We may consider a portion of the water to act as an incompressible body, which is depressed at one end by the added water, while at the other end it succeeds in raising a certain quantity. The relation of the quantity of water raised to the quantity depressed depends upon the sectional areas of the columns, and consequently upon the vertical displacements. It may be of value to note that the sectional areas of the columns in this experiment correspond with the arms of the lever.

44. The Internal Stress of Liquids.—The preceding observations having shown some conditions of equilibrium of liquids at rest, the internal state of such liquids remains to be investigated.

It may be noticed, in the first place, that in a given column of liquid the pressure increases with the depth, just as in the case of a solid. The pressure at the bottom of the regular liquid column A B (No. 1, fig. 19) varies directly with the linear height A B, just as in the case of a homogeneous solid of similar shape. The bottom of the vessel supports the quantity of matter in the vessel just as if it were a solid rod receiving no support from the sides. The stress between the matter and the earth is the same whether it is solid or liquid matter. With the arrangement here shown (No. 2, fig. 19) of a string passing over a pulley A and through a hole in the ground and greased plate P, fitting against the ground edges of the vessel V, the varying quantities of liquid added to V will be found to be balanced by proportional quantities of matter at

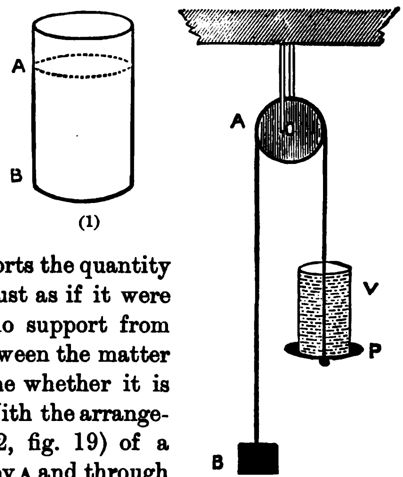
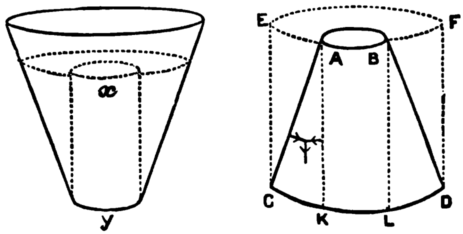


Fig. 19.

the other end (B) of the string. If the two portions of the string are vertical, or at the same angle with the vertical, equal quantities of matter at each end counterpoise—that is, the plate and the liquid will be equal to the quantity of matter at B. There is, therefore, no vertical support to the liquid from the sides of the vessel.

If we now immerse a thin plate in a liquid, and weigh it while immersed, as if its density were being ascertained, it will be found that it is counterpoised by the same quantity of matter at all depths.

The next observation is that the pressure at the bottom of a vessel depends in no way upon the shape of the vessel, or the



(3) (4)

Fig. 19.

quantity of liquid contained in it, but merely upon the linear vertical distance between the lower and upper surfaces of the liquid, and also, as we should expect, upon the area of the lower surface. Vessels of the shapes shown above (Nos. 3 and 4, fig. 19), together with the pulley and ground-glass plate, are sufficient to demonstrate this.

The following facts are therefore clear:—

1. That the vertical sides of the vessel (No. 1) do not support the liquid in the meaning of reducing the stress between the earth and the liquid.

2. That the sides of the vessel (No. 3) do reduce the stress to the extent that the bottom of the vessel only requires

to resist the stress between the earth and the imaginary column X Y.

3. That the pressure in a vessel of the shape shown in No. 4 is found to be the same as it would be if the sides were perpendicular, as C E, D F.

The pressure in the part A K L B (No. 4) is evidently due to the stress between the liquid and the earth, and no difficulty arises in this case. But we need now to explain why the pressure on the areas C K and L D is the same as if the sides C A and D B were vertical as C E and D F. In order to do this we must make the following assumption: 'that the stresses between the parts of a liquid at rest are always perpendicular to the surfaces of separation between those parts.' From this assumption we can deduce the following facts:—In the portion A C K are pressures perpendicular to A C and A K from the side A C and the column of liquid A B K L respectively, which produce a resultant pressure downwards, as shown in the figure. The pressure from A C, due to the narrowing of the vessel at the top, is found from the observation to be exactly equal to the pressure which the side A C would bear from the presence of the same liquid in a vessel of the shape and dimensions A C E.

From this it is evident that the whole pressure from the part A C K is due to two causes: the first is the pressure due to gravity, and the second is the resultant of the perpendicular pressures from A C and A K. These two pressures are together equal to the pressure which a column of liquid represented by E K would exert on the bottom of the vessel in virtue of the stress existing between it and the earth.

The fact that the pressure on the sides of a vessel varies with the depth also requires to be observed and explained. If we consider the liquid to be made of very small particles, it is evident the top particles press on the next, and so on until the pressure on the lowest particles is due to the sum of the pressures of all the particles above it. This pressure causes the particles to slip away at right angles towards the sides, thereby producing a pressure on the sides which increases with the depth.

45. The Relation between Mutual Displacements.—We have observed that a small quantity of matter undergoing a large displacement may be the means of displacing a large quantity of matter. That is, mutual changes occur in which unequal masses are equivalent in virtue of unequal displacements. The examples investigated have been the pulley, lever, and the displacement of a large quantity of liquid by a smaller. The conditions necessary in these and all other examples of the same kind of mutual change are that the numerical value of the mass multiplied by the numerical value of the displacement shall give equal products for each of the moving masses, that is, $m\mathrm{L} = \mathrm{M}l$.

This principle may be extended to phenomena which are not connected by material bodies. In the previous observations we have bars, cords, &c., connecting the mutually changing bodies. In these cases it follows of necessity that both changes must take place in the same time. The simultaneousness of the changes is a consequence of their mutual nature. We may, therefore, substitute speed for displacement in our conception of the phenomena, for the numerical value of displacement divided by the numerical value of time expresses the magnitude of speed. But it is important to note that the *direction* in which the bodies move is not the same—that is, this complex quantity (mass × speed), which is called *momentum*, is positive in the one case and negative in the other.

This principle obtains in every case of mutual change, whether the bodies concerned are connected in any way or not. The displacements are in opposite directions; they are equal if the masses are equal, but if the masses are unequal the displacements are inversely proportional to them. This is the principle contained in Newton's Third Law of Motion, according to which *reaction* is always equal and opposite to *action*—that is, the actions of two bodies upon each other are always equal and in opposite directions.

In order to demonstrate this principle completely, it would be necessary to find a system which is under the influence of its own mutual action alone. On the surface of the earth we

are limited in this and many other similar investigations by the enormous stress which exists between the earth and all bodies near it. We cannot, therefore, easily prove the equivalence of mutual changes. In all the previous experiments the displacement which has been measured has been a displacement in the direction in which this stress acts, *i.e.* in a vertical direction. In the case of bodies moving without friction over a smooth horizontal surface, there is no displacement possible from the stress between them and the earth, and the displacements due to mutual changes will not be interfered with. Glass balls of different sizes rolling over a horizontal glass plate would approximate to these conditions, and with them we can prove roughly that a small fast-moving body can produce the same effect as a large slow-moving body. By causing balls of various sizes to strike others at different rates this may be shown in a rough manner.

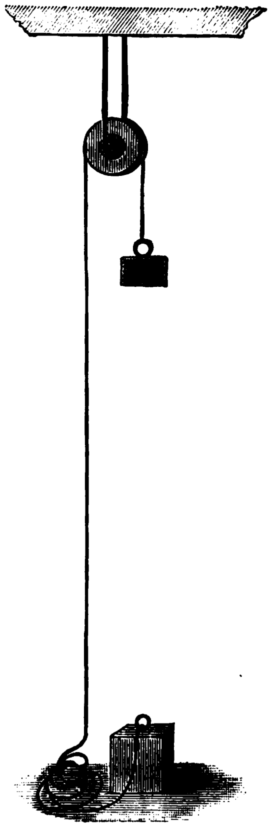


Fig. 20.

We may obtain similar results by fastening two unequal masses to a long cord passing over a pulley. If the heavier mass is supported, and the smaller mass allowed to fall for some time, and so acquire a speed before it begins to tighten the cord, it will be found that a rapidly-moving small mass is able to raise a much larger mass. The arrangement shown in fig. 20 will suffice for a number of observations. Similar results are observable in the use of a hammer or a pile-driver.

46. New Test for Equal Quantities of Matter.—Atwood's Machine.—By experiment with Atwood's machine it will be found that an additional mass, placed on one of the equal masses which are connected by the silk thread passing over the pulley, and allowed to fall for a measured time, will have acquired at the end of that time, together with these equal masses, a certain speed. This speed may be measured easily, for, if the additional mass be removed by a ring, the two equal masses continue to move uniformly with the identical speed which the system possessed at the moment of this removal. The uniform motion of the two equal masses after removal of the small mass which produced the acceleration, is a matter of direct observation which is in accordance with previous observations.

Those masses which, under the same conditions, acquire equal speeds are equal masses. Those masses are equal which, when added for an equal time to this system containing two equal masses connected by a string, produce in it equal speeds.

By the use of two similar pulleys, each with the same masses connected by a thread, a comparison of the speeds acquired may be made independently of the time taken. Direct observation of coincidence by sight and hearing will decide whether the speeds, and hence the masses, are equal. In this comparative method we are less dependent for accuracy on the smooth running of the pulleys. Provided they run alike, the conditions are the same for each change occurring.

We shall find later that other stresses, besides that existing between the earth and all bodies removed from its surface, may be utilised for measuring quantity of matter.

We must not forget that this instrument enables us to surmise the manner in which a body falls to the earth by causing it to fall slowly. This retardation is produced by causing the body to form part of a system of three bodies, two of which are equal in mass and connected by a string so as to be in equilibrium. The speed which this body acquires under various conditions is not directly measured, but is taken from the uniform speed with which the system moves

according to Newton's First Law of Motion, after the disturbing body is removed.

It is important to understand correctly the manner and degree in which this retardation is brought about. First of all, we learn from direct observation that the retardation is greater in proportion as the mass of the whole system is greater than that of the body under observation. That is, if the mass of the three bodies together is four times greater than the mass of the added body, then the speed acquired by this body in falling for one second will be 8 feet per second, instead of the 32 feet per second which it would gain in falling by itself for the same time. In order to have a clear conception of the cause of this change of speed, it is advisable to regard the arrangement of two perfectly equal masses, connected by a non-extensible string which passes over a pulley, as a system in equilibrium and ready to move in a vertical direction, just as if it were released entirely from the stress which exists between the earth and all bodies near it. As a matter of fact, the stress cannot be annihilated, and we have here two such stresses, exactly equal, but made by the string, which is said to be in a state of 'tension,' to counteract each other. (We have a similar counteraction of two stresses when equal masses are placed in the pans of a balance.) Under these circumstances we may regard the system, as it now is, to be just the same as any body placed in such a position in space that it is free from all stresses and, indeed, from all liabilities. This, however, is only true for any disturbance in a vertical direction, but it is only for observing such disturbances that it is used. When we come to place the additional mass on one of these equal masses, we make the whole system, *i.e.* the three bodies, participate in the effect of the stress existing between that additional mass and the earth. In other words, the change is spread out over three bodies, and the actual rate of motion is diminished in exact proportion to the relative increase in the quantity of matter taking part in the given change.

By these and similar observations we are led to the generalisation that, in any consideration of the effects of a given

stress (or force), we must pay regard both to the rate of change of speed and also to the quantity of matter in which it is produced.

Additional Exercises and Questions.

1. Why does water remain in a pipette when the upper end is closed?

2. Draw a diagram to explain how the reading of a barometer will be affected by a divergence of the instrument from the perpendicular.

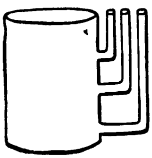


Fig. 21.

3. Observe the level of the liquid in the various branches of the vessel shown in fig. 21. How do your observations explain the relation of pressure to distance from surface?

4. What would be the pressure on—that is, what would be the quantity of matter supported by—a sheet of 1 square centimetre area placed at a depth of 1 metre in water? What is the pressure when it is placed in mercury? Why does the sheet not move downwards under this pressure, and how is that quantity of matter supported? It is assumed that the liquid is over 1 metre in depth.

5. Explain why a body immersed in a liquid is partially or completely supported by the liquid. To what extent is the body supported, and why does it depend on the volume?

6. When a solid floats on a liquid, what will determine how much is submerged below the surface of the liquid?

7. Observe and explain what takes place when a liquid (water, for example) in a beaker, and a solid with a piece of silk attached, are weighed when lying side by side in the pan of a balance; and also when the solid is suspended by the silk from the hook at the end of the beam and immersed in the water. Also observe and explain what takes place when a beaker of water is weighed, and then a solid hanging from an independent support is placed in the liquid. Prove that what the water appears to gain in this case is exactly the same as the object appears to lose if it is made to hang from the beam, while the water is supported independently, as in determining density.

8. Fill with water a tube which has been closed at one end, and is about a metre long, place the thumb over the end, and remove the thumb when the open end is underneath the surface of water in another vessel. Observe that the water remains in the tube when it is placed upright. Fill a similar tube with mercury and invert it over mercury, and observe that the whole column of mercury in the tube is not supported but sinks to a certain level. Observe also what occurs when the tube is not completely filled with the water or mercury, and likewise the alteration

of level produced by lowering or raising the tube. Write out an explanation of your observations.

9. Ascertain that a vessel may be emptied of a liquid by means of a bent tube, one end of which is at the bottom of the vessel and the other at a lower level outside the vessel. The air requires to be removed from the tube. Observe the conditions necessary for the commencement of the operation, and explain by the use of diagrams the cause of the change which goes on.

10. Demonstrate by the use of bent tubes of the shape shown in fig. 22, and containing mercury, (1) That the pressure of a liquid varies as the depth; (2) that the pressure is the same in all directions.

11. Compare the pressure of the coal-gas in the supply pipes with that of the atmosphere by noting the level of liquid (water or mercury) in each branch of a bent tube, one of which is exposed to the atmosphere, the other to the coal-gas. How will the result be affected by a difference in the section of the two branches?

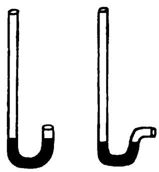


Fig. 22.

12. Insert two tubes in two vessels containing different liquids, connect them at the top by a T-shaped tube, and partially exhaust the air. Measure the length of each column, and calculate the relative densities of the liquids.

13. Describe from your own observations how air enters the lungs at an inspiration.

14. Explain clearly why a body immersed in a liquid has acting upon it in an upward direction a pressure, which would balance the downward pressure of a volume of the liquid equal to that of the body immersed. Make observations to demonstrate this statement.

15. Observe and explain what takes place when a tube closed at one end, and about 1 metre long, is completely filled with mercury and inverted over a vessel of water. Proceed cautiously at first, only partially removing the thumb.

CHAPTER V

OBSERVATIONS OF CERTAIN MUTUAL CHANGES EXHIBITED BY CERTAIN KINDS OF MATTER

47. When Certain Bodies are rubbed together and separated the Space near them exhibits Certain Properties.—The most distinctive feature, and the one most easily exhibited, of a so-called electrified body is that small portions of certain kinds of matter in its neighbourhood are set in motion.

This property may be shown by bringing a piece of sealing-wax, which has been rubbed on flannel or cloth, near to a piece of pith suspended by a silk fibre, or dry lath balanced on a blunt point. Rapid movement towards the sealing-wax or electrified body is seen, and sometimes the body after contact moves away, and sometimes there is a repeated to-and-fro movement. The region in which such displacements take place is called the *electric field.*

Amber, ebonite, glass, resin, gutta-percha, etc., rubbed with flannel, silk, fur, etc., exhibit the same properties as sealing-wax. These changes, however, do not take place until the object rubbed and the rubber are separated. When they are together brought near a light body no movement is noticed, although each apart may cause considerable movement. The act of separation is therefore essential.

When a metal is rubbed by a piece of silk and tested like the sealing-wax, no change is perceptible, but if the metal, conveniently in the form of a rod, is firmly fixed to a glass rod, which is held in the hand while the metal is rubbed, a movement of a light body may be obtained. When this class of bodies is touched by the hand, it suddenly loses this property.

This explains why it does not gain the property when held in the hand while being rubbed.

48. Communication of the Property to Other Bodies.—When an electrified body is brought near to, or in contact with, certain bodies, they may be shown to exhibit properties similar to the electrified body itself. It is only those bodies, however, which cannot be electrified unless held by a handle of glass, ebonite, etc., which can have this property communicated.

That kind of matter which suddenly loses when touched by the hand, or, if held by the hand, cannot acquire, this property, which may be termed 'electrification,' is called 'electrically conducting matter,' or a 'conductor of electrification.'

Good Conductors.	*Bad Conductors, or Insulators.*
Metals.	Gases.
Carbon.	Oils.
Water containing salts in solution.	Ebonite.
	Paraffin.
	Resin.
	Gutta-percha.
	Caoutchouc.
	Porcelain.
	Glass.
	Sealing-wax.
	Silk.
	Sulphur.
	Wool.
	Shellac.

49. Investigation of the Electric Field by a Small Elongated Body, and also by Two Small Bodies.—If a light elongated body—for example, a piece of pith suspended by a silk thread at the end of a stick—is brought into the space between two bodies which have been rubbed and separated, it is always caused to set itself lengthways between them. If displaced, it returns to this position, sometimes with the ends reversed.

If, however, instead of one elongated body, two small bodies, such as two pith balls suspended side by side, are

brought into the electric field, they will be found to diverge so that each approaches as nearly as possible to either of the two electrified bodies. Instead of two pith balls, two strips of gold leaf, hanging side by side, will be found to diverge very readily when placed in the electric field. The gold leaves belonging to the electroscope may be used.

Each of these experiments is now tried with either of the two bodies separated considerably from the other. Bring an electrified body, either the object rubbed or the rubber, near to an elongated body or two small bodies delicately suspended.

If a single small body is brought near to an electrified body

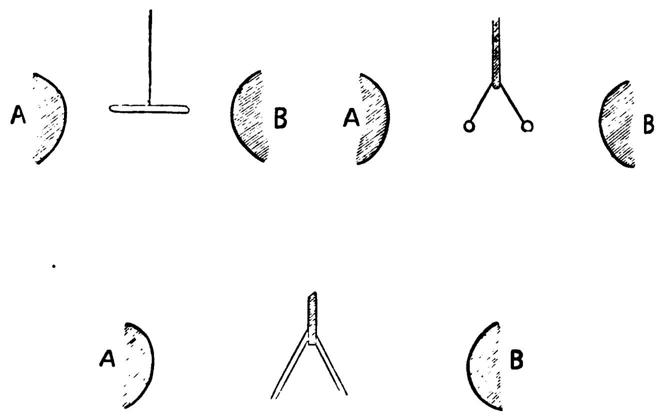


Fig. 23.

it moves towards it, provided the stress between that small body and the earth is not greater than the electrical stress. It either remains in contact with the electrified body, or, after contact, is repelled. If placed between two bodies that have been rubbed and separated, it will move quickly to and fro between them, if the distance is not too great. It must be noted, however, that it first moves towards that body which is nearest.

If the small body is itself in this electrified condition it will be either attracted or repelled by the larger electrified

body. The smaller body may be brought to this condition either by friction or by being placed in contact with an electrified body. The same effect will be produced in each case. That is, it is now in a condition such that it may be either attracted or repelled, according to circumstances, whereas a body which is not electrified is never repelled by an electrical body.

It will be seen that the behaviour just described explains why a body, which is not electrified, may be first attracted and then repelled by an electrified body.

A and B in each of the above diagrams are mutually electrified bodies, and the condition of the electric field is indicated by the behaviour of the bodies placed in it.

Additional Exercises and Questions.

1. Perform experiments with the view of finding out whether electrification is a property of matter or of space. Show, for example, that the space near an electrified body differs from other space.
2. Instead of saying that the condition of space is altered, we might say that an electrified body acts at a distance. Discuss this theory.
3. How would you investigate experimentally whether two bodies are in the same electric condition, and how would you ascertain if they are in equal electric conditions—that is, if they are equivalent in causing those changes which are characteristic of electrified bodies? How would your results be explained if you attribute the changes in question to a condition of space rather than to the condition of the material bodies engaged?
4. Do you consider the terms 'positive' and 'negative,' as applied to electrification, suitable?
5. Perform several experiments which show that electrification is a two-sided phenomenon.
6. Explain what is meant when it is stated that there are 'two kinds of electricity.'

50. The Existence of Electric Stress indicated by the Electroscope.—Two light bodies, for convenience, strips of gold leaf, are suspended side by side from a metal rod, and enclosed within a glass vessel for protection from currents of air. The metal rod may terminate either in a disc or a sphere. When

an electrified body, *e.g.* a piece of ebonite or sealing-wax which has been rubbed with flannel, is brought near the top of this instrument, the gold leaves move simultaneously. If the disc is now touched with the hand, the leaves return to their original position ; but if the hand first, and then the electrified body, be removed, the leaves again simultaneously diverge during the removal of the electrified body, and remain apart for some time.

It may be noted in the first observation, that the nearer the electrified body approaches the instrument the more the leaves diverge ; and in the second observation, that the leaves diverge the more widely the further away the electrified body is removed, after the disc has been touched by the hand.

This instrument, which exhibits very conveniently the condition of the electric field, and may be used for purposes of comparison, is called an electroscope. It is essential that the metal rod and leaves be well insulated.

We have observed from previous experiments that the effects produced by an electrified body depend upon the relative position, nature, and quantity of matter acted upon. The use of the electroscope, however, discovers another very important condition essential to the manifestation of electric stress, and this is a change in the configuration of the system concerned. However great the stress may be, it would be unobserved so long as the system is unaltered in configuration. It is not manifested except by certain movements taking place in a neighbouring body, or bodies, concurrently with a displacement in the relative position of the electrified body.

We have so far made use of the term, 'electrified body,' but it is now clear that it would be more correct to include in our observations all the bodies concerned in the mutual changes which are said to be due to electricity, and speak of them as 'the electrified system.' There is no indication of such a thing as an electrified body existing entirely by itself, or of electric changes in which only one body is concerned.

51. The Quadrant Electrometer.—The electric stress which has been produced by friction, or any other cause, may be further investigated by the use of an electrometer. The thin

gold leaves are replaced by a thin flat strip of aluminium, which is suspended by two silk fibres so as to hang horizontally within four hollow horizontal metal quadrants. The opposite pairs of quadrants are united by a wire, but they are otherwise quite separate from one another, and supported on glass pillars. The whole is covered by a glass case, and also by a metal framework which places the whole of the space around the electrometer in more perfect connection with the earth. Two pairs of quadrants may, by means of connecting metal rods, be placed in electric communication with two bodies which have been electrified. These pairs of quadrants now electrically represent, in a more investigable form, the bodies with which they have been placed in contact. Or rather, we add to our system another symmetrical system, which partakes of its electrical condition and exhibits it in a convenient manner. The aluminium vane may, if necessary, be electrified by communication with an external body, through the medium of hydrogen sulphate (contained in a vessel underneath) and platinum wires. These together connect the moveable vane with a metal rod, which leads outwards and turns on a pivot. The vane is made to hang so that it is midway between the two pairs of quadrants when they are not electrified. It moves to the one side or the other under different electric stresses; and the deflections are marked by the movement on a scale of a spot of light, which comes from a lamp, and is reflected from a small mirror attached to the plate. The essential structure of this instrument is here show in diagram (fig. 24).

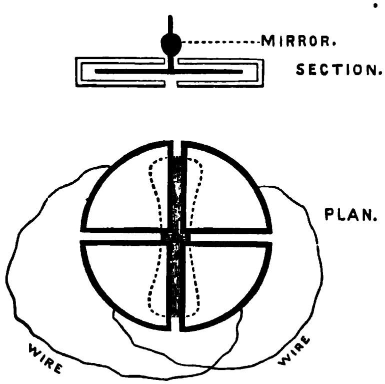


Fig. 24.

By the use of the quadrant electrometer we may perceive

when there is an electric stress between two bodies ; for then the vane or indicator moves, together with the spot of light on the scale. But we may also determine by its use a much more important matter, viz. which of two electric stresses is the greater. If one pair of quadrants is introduced into an electric system, the indicator will move towards or away from that pair, according to circumstances. If the other pair of quadrants is introduced into another electric system, so as to occupy a corresponding position in it, there will be a stress between this pair and the indicator which will oppose the first stress. The deflection of the indicator will show the relation between these stresses.

In the attracted-disc electrometer, the electric stress is compared with that of gravity—a stress which may be easily defined and measured, since it varies directly with the quantity of matter used. The electric stress between two opposed discs is accurately balanced, by a lever arrangement, with the stress due to a certain quantity of matter and the earth.

The stress existing between parts of a system similarly electrified may also be exhibited by the instrument shown in the diagram. A thick copper or brass wire circle or ellipse has two plates, A and B, attached in such a position that similar plates, C and D, at the end of a thin pointer may face them. This pointer is carefully balanced on the steel point E, and the whole is now supported on an ebonite pillar F. We obtain a system in complete electric connection, and able to exhibit stress between its parts without losing that connection. It should be covered just as the gold-leaf electroscope by a glass coated inside with strips of tinfoil. A plate G is attached so that the system may be electrified with convenience, whereupon, the pointer is repelled to a distance varying with the magnitude of the electric stress. Observations made with

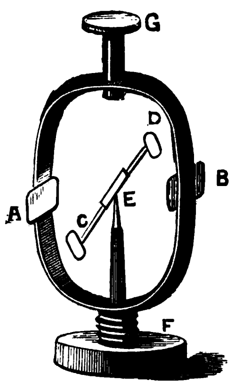


Fig. 25.

this instrument should be compared with those made with the gold-leaf electroscope. It will be found much less sensitive, on account of the greater quantity of matter displaced under the action of the stress.

52. Exploration of the Electric Field by Two Discs.—The neighbourhood of an electrified body is in such a condition that not only do conductors, whether electrified or not, tend to move, but also an electric change is induced in them, whether previously electrified or not.

Two similar metal discs with non-conducting handles are brought, with their faces in contact, into the electric field. If they are now separated in such a manner that they are placed at different linear distances from the electrified body, and then removed from the field, they will be found to possess the same properties as two bodies which have been together electrified by friction. This is proved by the behaviour of a small electrified body (a gilt pith ball), or by use of the electroscope or quadrant electrometer. If not separated before removal, no change takes place ; or if brought together after separation and removal from the field, no electrification can be further obtained.

The same condition of the field may be shown by electrically connecting a conductor on a non-conducting support to a distant electroscope or electrometer by means of a wire. On bringing the electrified body near the conductor, the leaves of the electroscope, or vane of the electrometer, will move and take up a fresh position so long as the electrified body is near.

If the conductor, while in the field, be touched by the hand and then removed, it may be shown, by applying any of the previous tests, to be electrified.

All the actions observed above will be found to diminish very rapidly as the distance from the electrified body increases, *i.e.* the nearer the body originating the changes, the greater will these changes be.

We may have a series of these phenomena caused by the same body, either simultaneously, in case there are several suitable bodies near, or successively, in case the body induced is removed from the system and then treated as the originating

body in a new system. In other words, this inductive action may affect a large number of bodies placed at increasing distances from the inducing body, the action diminishing with the distance. It may also be noted that the action depends solely on the linear distance, and not at all on the direction, provided that other bodies be not introduced into the field.

Additional Exercises and Questions.

1. Show that two mutually electrified bodies behave, when separated, as if they were joined by some extensible but elastic material.

2. Under what conditions may the electrification of a given body be communicated to a non-conducting body?

3. In the electroscope and electrometer, the bodies between which mutual changes are taking place are shielded or screened either by wire-work or tinfoil. Give reasons for this in each case, and point out any difference in their application to the two kinds of instruments.

4. Make experiments with a view to discovering the amount of electric change which can be produced within a hollow metallic body by means of an electrified body held outside. For this purpose introduce any instrument or system, which is sensitive to electric changes, within a wire cage or any hollow metallic vessel. Compare results both with and without contact between the body inside and the cage, and also when the hollow vessel is in itself strongly electrified.

5. Place a sensitive electroscope in metallic contact with a hollow vessel, and observe the effect of placing within the vessel a 'charged body,' and also of putting it in contact with the vessel from the inside.

6. From your observations of electrification what suggestion can you make as to their origin?

7. What experiments demonstrate that the origin of electric changes lies in the condition of the space around those bodies which manifest the changes, that this condition will vary with the nature of the substances also occupying the space in question, but that space which is filled by conducting matter cannot exhibit the properties of which it is otherwise capable?

8. Show that conducting matter may become electrified by friction if it is insulated. Place a metallic plate upon a sheet of ebonite or paraffin; connect the plate with an electroscope at a convenient distance, and rub it with a piece of fur. The electrophorus may be utilised for the purpose, but take care that the cake of ebonite itself is not electrified. Passing through a flame will discharge it.

9. Demonstrate that dry glass is an insulator, while moist or strongly heated glass is a conductor. In order to do so, arrange a piece of glass so that it forms part of the matter connecting an electrified body with an electroscope.

10. Two plates are carefully insulated and supported on a wooden base. Connect one with an electroscope and then electrify it. Observe the effects produced in the electroscope when the other plate is brought nearer to, and taken further away from, the plate connected with the electroscope. Frame some hypothesis in explanation of the changes observed.

53. Electric Phenomena Produced by another Method.— If two long strips of zinc and copper be placed, without touching one another, in dilute hydrogen sulphate, and then connected with the quadrant electrometer, a movement of the vane will be seen, just as with bodies electrified by friction.

If the two free ends of the strips are connected with two large plates placed face to face, a light suspended body may be caused to move, when placed between them, just as if these plates had been electrified by friction or induction. In the same way, too, the plates, if removed from the system by non-conducting supports, remain in the same condition for some time, but lose their property completely when made to touch. The space between the two strips or plates outside the liquid is an electric field of the same nature as the last investigated.

Any arrangement of material by means of which these results may be obtained, is called an electric cell, and there is great variety in the systems capable of being used. Several cells may be combined into a battery, so as to give greater results.

The Daniell cell consists of a copper plate, placed in a solution of copper sulphate, and a porous vessel containing zinc sulphate and a zinc rod or plate. All these are placed in an outer vessel, and connections are made from the copper and zinc. It will be found that the results, described above as obtainable from a cell, are independent of the size of any portion of the cell, and depend solely on the nature of the materials used.

In the Grove cell we have the zinc plate immersed in dilute hydrogen sulphate, in which is also placed a porous vessel containing strong hydrogen nitrate, and a sheet of platinum.

The Bunsen cell resembles the Grove, except that the sheet of platinum is replaced by a plate of carbon.

The Leclanché cell consists essentially of a carbon plate and a zinc rod immersed in a solution of ammonium chloride. The carbon plate, however, is packed with manganese dioxide and carbon fragments in a porous vessel.

The Bichromate cell consists of carbon and zinc plates immersed in a mixture of potassium bichromate and hydrogen sulphate, or in hydrogen chromate solution.

54. Processes by which Electric Equilibrium is effected.— If two conducting bodies, mutually electrified either by friction, induction, conduction, or by communication with a cell, are insulated, and placed close together, they may be caused to resume their normal condition by means of a small insulated conductor (a gilt pith ball for instance) suspended by a silk thread between them. This conductor will move to and fro between them with considerable velocity, making repeated contacts with each, which gradually diminish and cease. At this point the two bodies will be found to be no longer electrified, for with electroscopes and electrometers no indications of that condition are given.

These bodies may also be caused to resume their normal condition by placing a metal between them by means of an insulating handle. The change in this case takes place with extreme rapidity. It is effected by a momentary contact. At the same time the process is not visible. The change takes place without any displacement of matter. Any number of bodies, put in electric connection with one another by means of metals, immediately assume the same electric condition, whatever their original condition may have been.

If a piece of very thin wire is placed in connection with the two bodies, equilibrium is not reached so rapidly, and may take a measurable time. During the process which brings about equilibrium, the wire may be shown to be in a condition

which is commonly described as having a current of electricity flowing through it. This description has been so long used that it has become a familiar term, but subsequent investigation will show how far it is suitable or correct.

The nature of the material used for bringing about the equilibrium has an important bearing. Under ordinary circumstances air lies between the two bodies, but in this case equilibrium is indefinitely retarded. The same will be the case with glass, ebonite, and all insulators or non-conductors; but with conductors it takes place readily, and still more readily when the conductors are relatively large.

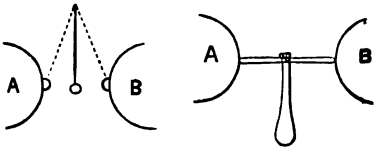


Fig. 26.

Two processes by which electric equilibrium may be brought about are shown above (fig. 26).

55. An Electric Circuit, Conditions necessary for.—If strips of copper and zinc are placed in hydrogen sulphate and put in metallic connection with one another outside the liquid, changes may be observed in the liquid and also in the zinc employed. Investigation will prove these changes to be permanent. When they cease, the system is no longer able to exhibit the electric properties of which it has already been shown to be possessed.

The same statement holds good for any of the other electric systems or cells. Co-existent with these changes there is one which is not apparent, but which may be perceived by special means. The space in the neighbourhood of the system is in a certain condition afterwards to be investigated, and we may speak of the bodies constituting such a system as an 'electric circuit.'

The quantity of matter in a circuit may be increased without any alteration in the nature of the properties acquired, provided the additional matter inserted is conducting matter; but the magnitude of the effects, characteristic of such a system, may be shown to vary with any change either in the

quantity, nature, dimensions, or temperature of any portion of that system.

It will afterwards be shown that we may have an electric circuit—that is, a system of bodies exhibiting special properties—without any permanent change of the kind about to be investigated. For the changes taking place in the cell some other kind of change may be substituted, so as to be correlative with the electric change. This may be a change of temperature or of position, as will be shown.

The kind of change taking place in a cell may be illustrated by the changes occurring in a zinc, copper, and hydrogen sulphate cell. When perfectly pure and homogeneous zinc is placed in dilute hydrogen sulphate, no action is observed. The quantity of zinc, on weighing before and after immersion, is found unchanged. Ordinary zinc, however, is acted upon by hydrogen sulphate, and diminishes in quantity by entering into solution, while the hydrogen sulphate itself becomes changed, losing a gas—hydrogen—and yielding on evaporation a white solid—zinc sulphate. Precisely these changes take place when pure zinc and copper are placed in hydrogen sulphate and connected electrically. Since copper itself undergoes no change, nor produces any change, in hydrogen sulphate, we may consider that the conjunction of the zinc and copper with hydrogen sulphate originates certain changes of the special kind known as chemical, and also that the behaviour of impure zinc is due to its impurities playing the part of copper in the above arrangement.

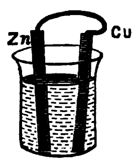


Fig. 27.

56. The Existence of Magnetic Stress Indicated by the Simultaneous Movement of Two Magnets.—When two magnets, freely suspended, are brought sufficiently near to one another, they will be found to mutually attract or mutually repel, according to circumstances. Or if one is set oscillating, the other will also oscillate.

In addition, any freely suspended magnet will always set itself in the same position with regard to the earth, lying nearly north and south. If one of the ends of the magnet is

marked, it may be perceived that this end will always point in the same direction. If it is displaced from this position, it will oscillate for some time, and then come to rest. It is also capable of moving in a vertical plane if properly suspended; it will be inclined in a degree which is found to vary in different places on the earth's surface.

We have, then, indications of a stress existing between a given magnet and the earth, and also of a stress between one magnet and another.

In these experiments, as in the experiments on electric stress, the suspension of the bodies used is necessary, in order to overcome the stress of gravitation existing between them and the earth. This stress is so powerful that those less powerful are prevented from producing their special changes.

When a suspended magnet is observed to place itself always in the same position with regard to the earth, and to oscillate about that position if displaced, we are unable to detect any change in the earth itself; just as we are unable to perceive any change of the earth co-existent with the fall of a body, but the mutual nature of the change is very readily seen in the case of the magnetic stress between two magnets.

A change, exactly corresponding with the oscillation of a magnet which has been displaced from its position of equilibrium, takes place when a suspended body, such as a pendulum, oscillates under the stress of gravitation.

If that end of a magnet which moves so as to point to the north is brought near the corresponding end of another magnet, the stress will be such that they are mutually repelled. If the two ends which point southwards are brought together, they are likewise mutually repelled. A north and a south-pointing end, however, mutually attract. This property is easily shown by suspending the magnets from their centres. Likewise, magnets placed lengthways near each other are attracted or repelled according as their corresponding ends are reversed or together.

We learn, therefore, that a magnet possesses polarity, or a dual variation in space, similar to an electric field.

57. Deflection of a Freely Suspended Magnet by a Substance forming part of an Electric Circuit.—When a lightly suspended magnet is brought near to a conducting body which is in connection with the copper and zinc of a cell, or which in any way forms part of an electric circuit, stress between them may be observed. The magnet always tends to take up the same position, for if displaced from this position it returns after some oscillation.

The magnet tends to place itself at right angles to that axis of the conductor which lies between the points of connection with the rest of the system. The relative distances from those points, or the plane in which the magnet is held, does not alter this tendency; but on increasing the distance from the conductor itself the stress rapidly decreases.

It is convenient to take a wire as the connecting conductor. The magnet will always tend to set itself at right angles to the wire. Since the stress between the wire and the magnet is the same in all positions, provided the vertical distance from the conductor be unaltered, the ends of the magnet are reversed when it is moved half-way round the wire, *i.e.* from above to below the wire, or from one side to the other.

If, then, the wire is turned upon itself, so as to form a loop, the stress is intensified; and still more so if the wire is wound into a coil containing many loops. A magnet suspended at the centre of a coil will indicate by its movement when the coil forms part of an electric circuit. Such an arrangement is seen in a galvanometer.

All magnets, when freely suspended, are always so turned that their position with regard to the earth is the same. There is a distinct stress between them and the earth. Consequently, the displacement produced on a magnet by a conductor in a circuit must depend on the relative magnitude of the two stresses; and consequently, the magnet will sometimes only tend to set itself at right angles to the coil.

From this fact we learn also that the position of the conductor or coil in a galvanometer must not itself be at right angles to the position which a magnet assumes on account of

the stress between it and the earth, for then the other stress might be unnoticed.

58. Construction of a Galvanometer.—The stress existing between a coil of wire forming part of an electric circuit and a magnet is made use of in the instrument called a galvanometer. The simplest form of galvanometer consists of a number of turns of copper wire, which is insulated by a silk or cotton covering, wrapped round a wooden bobbin and supported vertically. The ends of the wire are connected by two binding screws, by means of which the galvanometer can be

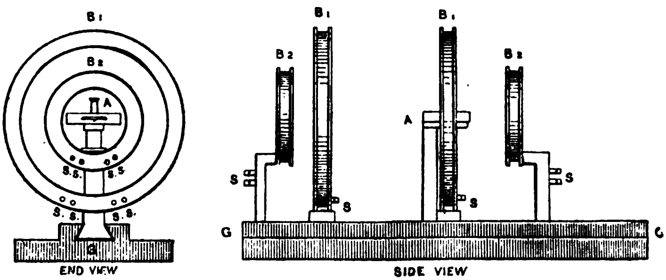


Fig. 28. Represents an Instrument for Showing the Action, upon a Magnet, of Coils Forming Part of an Electric Circuit.

A = magnetic needle with scale.
B_1, B_1 = wooden bobbins, each with two sets of coils and binding-screws S to correspond, one set of coils containing twice as many turns as the other.
B_2, B_2 = wooden bobbins with two coils like B_1 and B_1, but the diameters are just half those of B_1 and B_1 and their supports enable them to be placed in the same plane as the larger bobbins.
G = groove in which the four bobbins may slide, so as to vary their position with regard to the magnetic needle.

made to form part of an electric circuit. At the centre of this coil of wire is fixed a glass-covered box, containing a magnet suspended at its centre by a silk fibre. Underneath the magnet is placed a graduated circle, by which we may read the angle through which the magnet is deflected.

Since the magnet will always be turned in the same direction by the mutual action between it and the earth, the galvanometer is always placed so that its coil lies in this plane. Any movement of the magnet must then be due to the stress caused by the electric circuit. This stress will be found to

depend upon the number of turns of wire employed in making the coil, and also upon the diameter of the coil. Other things being the same, the stress varies directly with the number of turns, and inversely as the diameter of the coil. Very sensitive galvanometers are constructed by using a very large number of turns, closely surrounding small magnets delicately suspended by silk or quartz fibres. The deflecting power of the coil is also made more apparent by using several very small magnets pasted at the back of a small mirror, from which a spot of light from a lamp is reflected to a scale. A small movement of the magnets gives a large deflection of the spot of light on the scale. When a steady deflection has been produced in a galvanometer, the stress between the magnet and the earth is just balanced by the stress between the magnet and the coil in an electric condition.

59. Meaning of 'Conductivity.'—If a delicate electrometer is placed in connection with any two points in an electric circuit, it will indicate the existence of a stress. If these two points are altered, so that the length of the conductor between them is increased, the stress will be observed to increase, while it decreases if the length of the conductor diminishes. The greatest value is obtained when the electrometer is connected with the zinc and copper plates themselves (or their equivalents). This stress continues so long as the system is unaltered, and so long as the correlative chemical changes in the cell proceed. That is, the same properties are exhibited by every portion of the circuit as are shown by the conductor connecting two mutually electrified bodies; but while the latter condition is transient only, the other is maintained so long as certain changes proceed in the cell.

This stress varies with the nature of the substances forming the system, as was observed in the use of the galvanometer. When a bad conductor, such as bismuth, is inserted, the stress for the same length is much diminished, and may not be perceptible. At the same time, any alteration in the dimensions of the conductor inserted will affect the stress. The thinner the conductor, the smaller the stress, provided other things remain unaltered. Also, addition to the quantity

of matter forming the circuit may diminish the stress, and so much may be added as to render it imperceptible. This, however, will not readily happen unless the matter added is a bad conductor by reason of its nature or thinness. If any portion of the circuit is much changed in temperature, the stress varies, a rise in temperature generally causing a diminution.

All these phenomena may be exhibited by using a galvanometer as well as by using an electrometer.

We observe, then, that different kinds of matter have different effects upon the stress shown by an electric circuit. If that portion of the circuit which is called the cell or battery remains unaltered, the stress obtained will vary with the quality, dimensions, quantity, and temperature of the rest of the circuit. When the dimensions, quantity, and temperature are kept the same, then the stress varies with the nature of the matter employed. When the stress is large, the matter is said to have good conductivity, and the value of the stress varies with the degree of conductivity. In practical application the term 'resistance' is more general. The greater the stress, the lower is the resistance. The value of resistance will therefore be the reciprocal of that of conductivity, and the use of either will lead to the same result. It is easy to see that both terms have their origin in the hypothesis of a current.

It is important to note that the relations existing between the stress and the matter in a circuit contained in it are also observed to exist between the rate at which the process of electric equilibrium takes place and the matter by which it is effected. Hence we may regard an electric circuit as caused by a system in which a state of equilibrium might readily occur but for some process by which it is constantly disturbed.

60. Change of Temperature in a Substance forming part of an Electric Circuit.—In addition to the stress which is shown either by the movement of a magnet or the index of an electrometer, it will be found that the whole of an electric circuit changes in temperature. The change will vary in different portions of the circuit, according to the nature and dimensions of the substances comprising it.

This change may be shown by using a thermometer, which,

when placed in the liquid of a cell, will indicate a rise of temperature when the circuit is closed. At the same time, another thermometer, in contact with another portion of the circuit, may indicate a rise in temperature, which will not necessarily be the same as that taking place in the cell.

The extent of the change of temperature may vary very much in different portions of the circuit; but the changes of temperature are alike in those portions where the dimensions and quality of the matter investigated are precisely alike.

At the same time, the change of temperature varies with the stress in the circuit, or, as it is called, the strength of current; and this change takes place proportionally throughout the circuit. The electric stress may readily be caused to diminish by adding to the circuit a body of low conductivity, such as a long, thin wire. A comparison may then be made of the relative changes of temperature in the same substance. The variation of the stress may be observed by the deflection of the magnet of a galvanometer, which is made to form part of the circuit. It is advisable to wrap a certain length of wire round the bulb of a thermometer and place them both in a vessel of water. The wire is then connected with the rest of the circuit. In this way a change of temperature is readily observed. The rise of temperature will be found to depend upon the time during which the circuit is closed.

The conductivity of metals diminishes with a rise in temperature. The conductivity of saline solutions, on the other hand, increases rapidly with a rise in temperature.

Approximate Relative Conductivity at 0° *C.*

Mercury unity.

Mercury	1·0
Silver, annealed	63·0
Copper "	59·0
Gold "	44·0
Aluminium, annealed	31·0
Platinum "	10·0
Iron "	9·2
Zinc, pressed	16·0
Tin "	8·2
German-silver, hard or annealed	4·2
Brass	17·2
Lead, pressed	4·6

Resistance of Hard-drawn Copper Wire at 15° C. according to New Standard Wire Gauge. Resistance is the Reciprocal of Conductivity. Density of Copper =8·95.

S. W. G.	Diameter in Centimetres	Resistance in Ohms per metre	Mass in Grams per metre	Nearest B. W. G.
7/0	1·270	·000137	1134·0	
6/0	1·179	·000159	976·3	
5/0	1·097	·000184	846·3	
4/0	1·016	·000215	725·6	
3/0	·945	·000248	627·6	
2/0	·884	·000283	549·6	0
0	·823	·000327	476·1	
1	·762	·000381	408·1	
2	·701	·000451	345·4	
3	·640	·000541	288·0	
4	·589	·000638	244·1	
5	·538	·000764	203·8	
6	·488	·000931	166·8	
7	·447	·000111	140·5	
8	·406	·00134	116·1	
9	·366	·00166	94·0	9
10	·325	·00210	74·3	11
11	·295	·00255	61·0	
12	·264	·00317	49·0	
13	·234	·00406	38·4	14½
14	·203	·00536	29·0	
15	·183	·00662	23·5	
16	·163	·00838	18·6	16
17	·142	·0109	14·2	
18	·122	·0149	10·4	
19	·102	·0215	7·26	
20	·0914	·0265	5·88	27
21	·0813	·0335	4·64	21
22	·0711	·0438	3·56	
23	·0610	·0596	2·61	
24	·0559	·0709	2·19	24
25	·0508	·0858	1·80	26
26	·0457	·106	1·47	27
27	·0417	·128	1·22	
28	·0376	·157	·893	
29	·0345	·185	·839	
30	·0315	·223	·697	31
31	·0295	·225	·610	
32	·0274	·294	·529	
33	·0254	·343	·453	32
34	·0234	·406	·384	
35	·0213	·486	·320	
36	·0193	·594	·262	36½
37	·0173	·742	·210	
38	·0152	·954	·163	
39	·0132	1·27	·123	
40	·0122	1·49	·104	

61. Formation of an Electric Current when Two Different Metals are placed in Contact at each Extremity, and the Two Junctions maintained at Different Temperatures.—Copper and iron wires, joined together and connected at their free ends with a galvanometer, will also serve to exhibit a relation between thermal changes and electric changes. If the junction is now warmed by any hot body, such as a flame, the magnet of the galvanometer will move. If the junction is cooled, the magnet will move in the opposite direction.

The simplest system would be a loop as shown (fig. 29, *a*), but the introduction of a galvanometer or electrometer into the circuit is needed to show the electric change produced by the change of temperature. The whole of the galvanometer coil may be considered as forming part of the copper wire, in

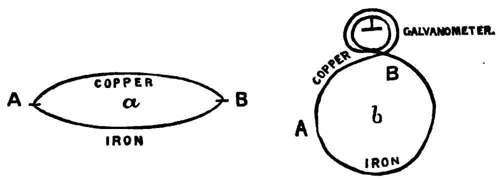


Fig. 29.

which case the two junctions will be at A and B as shown (fig. 29, *b*).

A system of this kind resembles the systems previously investigated, except that the cell is now absent. In the place of the cell, and fulfilling its function, we have a hot body and a junction of two kinds of matter.

The greater the difference of temperature maintained between the two junctions, the greater will be the electric stress produced up to a certain limit.

The important correlation between electric change and thermal change is illustrated in another manner.

If the temperature of junctions in a heterogeneous circuit containing a cell be carefully observed, it will be found that at some parts there is a fall of temperature, at others a rise. The direction of the change, however, is always the same for

the same arrangement of the circuit. In this case the electric stress causes the thermal change. In the previous case the thermal change caused the electric stress.

Additional Exercises and Questions.

1. How do you distinguish air, copper, brass, mercury, solution of copper sulphate in water, alcohol, turpentine, and glass with regard to conduction? Give experiments which would support your views.

2. What may be observed when conduction takes place in homogeneous metals?

3. What analogy exists between a current of electricity and a current of liquid?

4. Compare thermal conduction with electric conduction in the case of metals.

5. What units can you suggest in order to measure 'quantity of electricity' and 'current'?

6. Describe by means of diagrams the stresses in an electroscope and an electrometer, (1st) when they are at rest and not electrified, and (2nd) when they are at rest and electrified.

7. What experiments show that the space around bodies forming part of an electric circuit differs from ordinary space, and also from the space in the neighbourhood of an electrified body? What further distinctions can be drawn from the facts that conductivity increases with the sectional area, and that the whole of the body in an electric circuit changes in temperature and not merely the outside?

8. Coil a long piece of insulated wire into a helix, connect it horizontally by its two ends with a small cell which can be made to float in water, and observe that the coil sets itself with its axis nearly north and south, as a freely suspended magnet would do. Observe also that two such floating coils attract and repel just as two magnets free to move would do. The cell may be made of any suitable materials.

9. Construct a coil of insulated wire containing many turns, connect the ends with a galvanometer placed at some distance, and observe what happens when a bar magnet is moved in the axis of the coil, or when the coil is moved towards or away from the magnet. Note the result of variation in the rate of the movement.

10. Substitute for the magnet in the last observation (9) another coil in which a current is flowing. We then have a current in one coil producing a current in a neighbouring coil. Observe also that a bar of soft iron placed within the coil possesses the properties of a magnet as long as the circuit is unbroken. It becomes an electro-magnet. Insert

a key, and observe what occurs when the circuit is completed and also when it is broken.

11. Introduce wires of different thickness and different lengths (*e.g.* Nos. 16, 20, 32, and 40 B. W. G.) into a given circuit together with a galvanometer, and observe the effects.

12. Give some demonstrations of Ohm's law—viz. that the 'strength of current' varies directly as the 'electromotive force' and inversely as the resistance.

13. Construct a coil which possesses a resistance of 100 ohms by winding upon a reel some No. 32 silk-covered wire, German-silver preferably. Compare the wire before winding with a standard 100-ohm coil. After adjustment wind doubly from the middle, so that the coil may not possess magnetic properties (in this case there will be an equal number of turns in each direction, and, therefore, magnetic equilibrium). Solder the ends to terminals and coat with paraffin. The coil will probably be slightly inaccurate when carefully tested, but the experience will be valuable. Remember that the wire twisted round a binding-screw must not be counted as offering resistance.

14. Observe the effect of joining the terminals of a galvanometer by thick and thin wires while it is connected with the same battery. How would you prove that, when there is a choice of paths for the current, as in this case, the quantity along each path varies inversely as the resistance?

CHAPTER VI

OBSERVATIONS WHICH LEAD TO THE THEORY THAT ALL MATTER IS MADE UP OF VERY SMALL SEPARATE PARTICLES

62. When Liquids differing in Composition are placed in Contact a gradual Rearrangement of the Matter may proceed until the whole is homogeneous, i.e. until the Composition is the same in every Part.—The change by which two liquids spread themselves through one another so that in course of time the whole is alike in composition, is called diffusion. It will be found to take place in gases as well as liquids. Some liquids, however, remain distinct, and do not diffuse even when left in contact for a very long time. Such cases are illustrated by mercury and water. Mercury added to water sinks below the water, and their surface of separation does not change. In other cases, however, the surface of separation disappears more or less rapidly, the different kinds of matter cross the original surface of separation in each direction, and gradually become evenly distributed.

When a liquid and a gas are in contact the same kind of change may go on. For example, when water and air are in contact, some of the water passes into the air and some of the air into the water; but the substances differ so much in condition that the laws which hold for substances in the same condition do not apply. The solution of gases in liquids, and the evaporation of liquids, are treated separately. But within certain limits we may consider that if we have any two kinds of matter, x and y, in contact there is a tendency for the original surface of separation to become divided into two surfaces, which ultimately diverge as completely as

possible. Finally, no region contains x alone and no region contains y alone—at any rate, so far as we can yet analyse.

This action may be readily shown by placing a small flask containing alcohol within a large cylinder (fig. 30), and filling the cylinder gradually with water, which is denser than the alcohol, until its level is about 2 inches above the top of the flask. A glass bulb, blown so as to just float in water, and placed in the cylinder, will be found to sink lower and lower as the density of the liquid in the cylinder diminishes with the progress of the diffusion. When the diffusion is complete, the density of the liquid in the flask will be found, on removal and examination, to be the same as that in the cylinder. That is, the liquids will be evenly mixed by a process which cannot be directly traced nor explained, unless we admit that it is by the imperceptible movement of very minute particles of each liquid.

Fig. 30.

This action may also be illustrated by placing, by means of a fine pipette, a coloured liquid, such as a solution of potassium bichromate, at the bottom of a cylinder already filled with water. With care, little disturbance of the water will ensue. The diffusion may then be observed by the gradual change to a uniform tint throughout. Other methods will suggest themselves. The rate of diffusion varies with the kind of matter used; but in all cases the rate increases with the temperature.

63. When a Solid and a Liquid are placed in Contact, the Solid tends to gradually diffuse throughout the Liquid, in Amount dependent upon their Relative Quantity and their Nature and Temperature.—If water is the liquid selected, and sodium chloride the solid, it will be found that a small quantity of the solid, introduced into the liquid, will rapidly disappear or dissolve. A further quantity may be added and the same change ensues, and so on until a limit is reached. The solid does not then dissolve, but sinks to the bottom.

The solution of a solid in a liquid differs, therefore, from the mixing of two such liquids as alcohol and water, inasmuch as it cannot proceed indefinitely. It resembles it, however, in the peculiar thoroughness with which the solid permeates the whole of the liquid. In other words, the solid, or the dissolved portion of it, diffuses through the liquid, so that after a time the whole is homogeneous. This may be proved either by chemical means; by the evenness of tint when the solid is coloured; by the evenness of density; or by taking equal volumes of the solution, evaporating, and weighing the solid residue. The last process is generally applicable.

The rate at which a solid dissolves depends upon the extent of the areas in contact; hence a powder dissolves more quickly than the same quantity of the substance in one piece. It also depends upon the quantity of the solid already dissolved. A given liquid cannot hold dissolved more than a certain quantity of a given solid. In considering the process of solution, it must be remembered that the layer of liquid in contact with the solid becomes saturated—that is, it contains its maximum quantity, except so far as it loses by diffusion. This process, however, is slow. Hence movement quickens solution. For the same reason solution is often quickened by suspending the solid at the top of the liquid solvent, so that the denser saturated portions may sink away from the solid.

The limitation to the mixing of a solid with a given quantity of liquid must be looked upon as due to the solid itself rather than to any inability in the liquid. The knowledge which we have previously gained of the different behaviour exhibited by solids and liquids when acted on by stresses, gives a probability to the view that a solid consists of small particles which can only be separated with difficulty. The actions between a solid and its solvent, whatever they may be, which result in these firmly cohering particles being separated, are gradually weakened as more and more of the solid becomes mixed with the solvent. That the action is a complex one is proved by the fact that solubility is in no way proportional to tenacity.

64. The Solution of a Solid is attended with Change of Temperature. Also the Rate of Diffusion varies with Temperature. When ammonium nitrate is added to water the temperature is very much lowered; a temperature as low as $-27°$ C. may even be reached. Ammonium chloride, sodium acetate, silver nitrate, and potassium iodide, among others, will produce a fall of temperature. On the other hand, manganous sulphate, magnesium chloride, and a few others, when dissolved in water, cause a rise of temperature. The observations are easily made by using a thermometer to indicate the temperature before and after the solid in question is dissolved.

In all the above cases the solids dissolved resume their original condition on raising the temperature of the solution sufficiently to gasify the water, and the same observations may be made with other solids and other liquids. In certain cases, however, the solid cannot be restored to its original condition by raising the temperature of the liquid containing it. For example, when zinc and hydrogen sulphate are placed in contact, and the liquid afterwards raised in temperature, a solid quite unlike the zinc is obtained. Changes of this kind will require to be afterwards considered more fully by themselves.

In either case the change coincides with a thermal change, and at the same time cannot be mentally grasped, except as a rearrangement of very minute particles; those of one substance making their way among those of the other substances imperceptibly, just as imperceptibly as electric and thermal changes proceed. We adopt, then, the theory that matter is discontinuous, *i.e.* built up of separate particles. So small, however, are the particles that no changes which affect them can be directly observed, and hence the difficulty in measuring or understanding them.

It is important to note, in view of a possible connection between the temperature of a body and the motion of its minute particles, that the rate of diffusion of two liquids increases with the temperature.

65. The Quantity of a given Solid dissolved varies with the Temperature of the Solvent. The Point of Saturation is

reached by Different Quantities at Different Temperatures.—It will be convenient to take water as the solvent, and potassium nitrate as the solid. It will be found that water at about 55° C. will hold in solution three times as much potassium nitrate as the same quantity of water at 15° C. This may be shown by allowing water to remain in contact with excess of the solid (*i.e.* more than can be dissolved by the water) for several

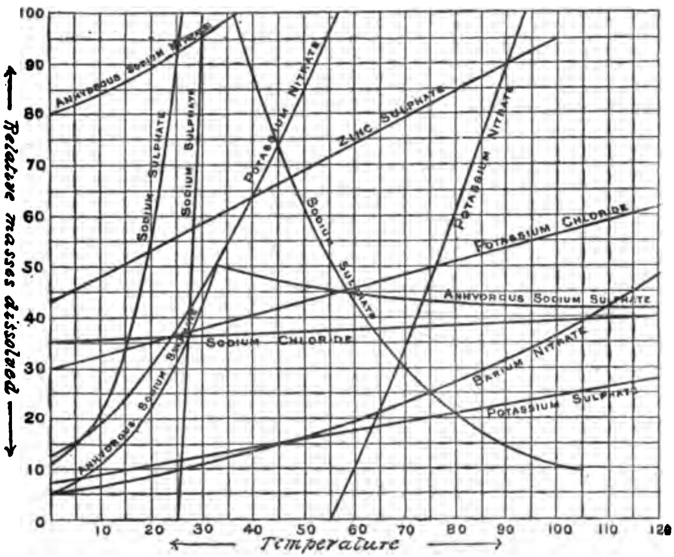


Fig. 31.

hours. A known quantity of the solution, which will then be at the temperature of the room, is then removed by a graduated pipette, placed in a crucible which has been previously weighed, and kept at a moderate temperature until all the water is gasified. Care must be taken that none of the solid is lost in the process. The crucible, with the solid, is then weighed, and the quantity held in solution thus determined. The quantity dissolved at a higher temperature may be ascertained by keeping the water, which is in contact with excess

of the solid, for some time at a temperature exceeding the temperature to be investigated. It may, for example, be boiled for several minutes. A thermometer is then inserted, and, as soon as the liquid has cooled to the desired temperature, the same quantity of the solution is transferred by a warm pipette to a weighed crucible, evaporated, and measured as before.

It follows from this that a saturated solution, as it cools, must liberate some of the solid from solution. This may be seen by allowing some of the warm solution to cool in a clean vessel. The solid then appears as crystals, first minute, then growing larger and increasing in number.

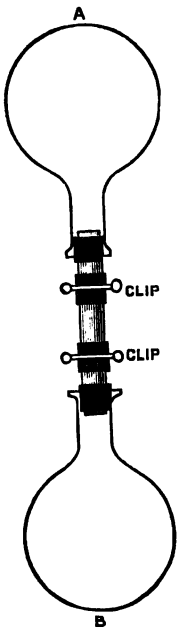


Fig. 32.

By this and other methods such diagrams as that of fig. 31 have been drawn up. The curves represent the relative solubilities of various substances at various temperatures.

66. When Gases differing in Composition are placed in Contact, a gradual Rearrangement of the Matter proceeds until the whole is homogeneous, i.e. until the Composition is the same in every Part.—In the same way as certain liquids diffuse throughout each other, so do gases; but the diffusion is completed, in the case of gases, more rapidly, even when the surfaces in contact are very small. The manipulation of a gas is more difficult than that of a liquid, and direct proofs of the diffusion of gases are scarcely needed in the presence of many indirect proofs, but the following experiment illustrates the diffusion of two gases into one another :—

Two dry glass flasks (A and B) of equal capacity, each fitted with a cork and glass tube to which a piece of caoutchouc tube with a clip is added, and containing air and ammonia respectively, are placed in communication by a narrow tube, and the clips opened so that the two gases may come into contact.

After some time the clips are turned, and the vessels disconnected and opened under water. The water will be found to rise about half-way inside each vessel, on account of the solubility of a portion of the contents of each vessel. Thus it is demonstrated that the ammonia which previously filled the upper vessel has evenly distributed itself throughout both vessels. The experiment also illustrates the fact that the gases are soluble in liquids, for the water entering into the vessels replaces the ammonia removed by solution. It is convenient to use, as the source of the ammonia for filling B, a strong solution of the gas in water, placed in a flask, fitted with a delivery tube which leads to the top of B, inverted over it. On raising the temperature of this solution, ammonia will be driven off and completely fill the vessel B, expelling the air downwards. This depends upon the fact that the quantity of gas dissolved by a liquid varies with the temperature. The higher the temperature the smaller is the quantity held in solution.

Table of Solubility of Air in Water.

Unit Volume of Water at 760 *m.m. pressure dissolves at:—*

Temperature	Volume of Air	Temperature	Volume of Air
0	·02471	11	·01916
1	·02406	12	·01882
2	·02345	13	·01851
3	·02287	14	·01822
4	·02237	15	·01795
5	·02179	16	·01771
6	·02128	17	·01750
7	·02080	18	·01732
8	·02034	19	·01717
9	·01992	20	·01704
10	·01953		

67. Atmospheric Pressure and its Variations.—An instrument for indicating the pressure of the atmosphere is called a barometer. A glass tube, of the form shown in fig. 33, closed at the end A and open at the end B, is nearly filled with mercury

Table of Coefficients of Absorption of Several Gases in Water and Alcohol at 0°, 4°, 10°, 15°, *and* 20° *C.*

Gas	Liquid	0°	4°	10°	15°	20°
Nitrogen . . .	Water	0·02035	0·01838	0·01607	0·01478	0·01403
Nitrogen . . .	Alcohol	0·12634	0·12476	0·12276	0·12142	0·12038
Hydrogen . . .	Water	0·01930	0·1930	0·01930	0·01930	0·01930
Hydrogen . . .	Alcohol	0·06925	0·06867	0·06786	0·00725	0·06668
Oxygen	Water	0·04114	0·03717	0·03250	0·02989	0·02838
Oxygen	Alcohol	0·28397	0·28397	0·28379	0·28397	0·28397
Carbon dioxide . .	Water	1·7987	1·5126	1·1847	1·0020	0·9014
Carbon dioxide . .	Alcohol	4·3295	3·9736	3·5140	3·1993	2·9465
Carbon monoxide . .	Water	0·03287	0·02987	0·02635	0·02432	0·02312
Carbon monoxide . .	Alcohol	0·20443	0·20443	0·20443	0·20443	0·20443
Hydrogen sulphide .	Water	4·3706	4·0442	3·5858	3·2326	2·9053
Hydrogen sulphide .	Alcohol	17·891	15·373	11·992	9·539	7·415
Sulphur dioxide . .	Water	79·789	69·828	56·647	47·276	39·374
Sulphur dioxide . .	Alcohol	328·62	265·81	190·31	144·55	114·48
Ammonia . . .	Water	1049·6	941·9	812·8	727·2	654·0
Air	Water	0·02471	0·02237	0·01953	0·01795	0·01704

by inclining it suitably. Any air now remaining may be swept out, by closing the open end with the thumb, and causing the air in the shorter branch to pass to the top of the longer branch and down again. Mercury is now poured out until it stands about half-way up the shorter branch, and the tube is supported vertically. It will be noticed that there is an empty space at the top A, provided the tube be long enough to allow the vertical distance between the two columns to be more than 760 m.m. If the tube be now attached to a graduated scale this vertical distance may be exactly measured, and observations will reveal variations from time to time.

Fig. 33.

The vertical distance between the two surfaces of mercury may be most accurately measured by using a cathetometer, which is an instrument consisting of an accurately graduated and rigid bar firmly fixed on a support carrying levelling screws, by which it may be made perfectly vertical. Spirit levels fixed upon a moveable portion will show when this condition is reached. To the moveable portion is rigidly fixed the reading telescope, which revolves in a horizontal plane only, and a vernier which is so arranged that the vertical movement of the telescope may be accurately read. The cross-wires of the telescope are first of all focussed upon some distant object, and then the telescope replaced in position. The vertical distance between any two points is then equal to the distance obtained from the readings of the vernier, although the telescope may have been moved horizontally through any angle in making the cross-wires coincide with the required points.

68. The Use of the Cistern Barometer.—The cistern barometer consists of a long straight tube, closed at one end, which has been completely filled with pure mercury and then inverted in a cistern holding mercury. The atmosphere, pressing upon the surface of the mercury in the cistern, supports a column of mercury within the tube, just as the atmospheric pressure on the surface of the mercury in the shorter limb of the tube,

which was used in the last experiment, maintained a longer column of mercury in the other limb. The height of the column supported may be noticed to vary slightly at different times, provided the tube be long enough. In order to accurately measure this variation in the distance between the level of the mercury in the cistern and that in the tube, certain details of construction are required. The bottom of the cistern A is formed of leather, which can be raised or lowered by a screw B working against it. By this means the surface of the mercury in the cistern may be always made to touch an ivory pointer C, placed immoveably with regard to the scale. The distance is then always measured from the bottom of this pointer to the top of the column of mercury within the tube, and since the scale is rigidly fixed to the tube (for it is marked on the brass tube partly encasing it), a band with a horizontal lower edge, moving over the tube and graduated so as to form a vernier, enables the exact position of the column with regard to the scale to be read. When the centre of the mercury surface and the front and back of the band all seem to be at the same level, their vertical heights coincide. It will be noticed that the surface of the mercury is somewhat convex. We measure from the centre of the surface, which will be the highest point, provided the tube be vertical. This is ensured by allowing the tube with its brass case to hang freely.

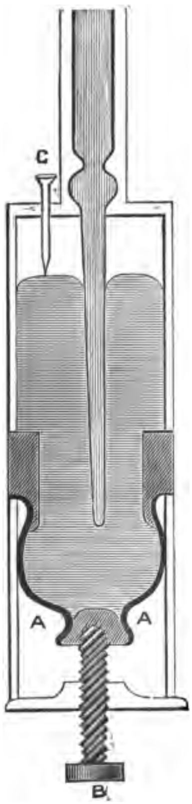


Fig. 34.

The accurate comparison of the pressure of the atmosphere at different times requires more than the reading of the height of the column of mercury it supports. The height of the column of liquid supported under these conditions has been shown to be inversely proportional to the density. The

density of mercury varies with its temperature. Hence the height must always be corrected to the same temperature for the comparison to be exact. In addition, the scale itself varies with change of temperature. If we know the coefficient of expansion of the brass of which it is made, correction is very easy. It is useful to take the heights of the columns of two barometers at the same time and note that they are alike, in so far as they are correctly constructed, although the tubes may vary in diameter.

69. The Volume of a given Mass of Air maintained at the same Temperature varies inversely as the Pressure, that is, the Density of Air varies directly as the Pressure.—A long thick glass tube of even bore, closed at the end A and enlarged at the other end B (fig. 35), has mercury carefully poured in until it stands at the same level in both limbs. This may be readily ascertained by a scale fixed behind, or better, by using the cathetometer. The height of the barometer is now taken, and then mercury added until the difference between the two levels is equal to the observed height of the barometer. It will now be found that the air in the shorter limb occupies half its previous volume, and it is evidently subject to double its original pressure—that is, double the pressure of the atmosphere. It is necessary to calibrate the shorter limb in order to measure the volume exactly. If, instead of adding a column of mercury equal to that supported in the barometer, we pour in mercury to half this height, the gas will be found to occupy two-thirds its original space; for the change of pressure is in the ratio of 1 to $1\frac{1}{2}$ or 2 to 3, and, therefore, the volume changes in the ratio of 3 to 2. It must be remembered, however, that a given change of pressure might not produce the same change of volume at different temperatures. In order to ascertain this, the changes in volume may be observed when the tube is surrounded as completely as is practicable by snow or ice,

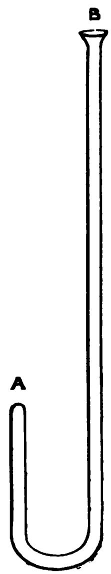


Fig. 35.

Observations at higher pressures require inconveniently long tubes ; but they have been found by special experiment not to agree exactly with the results at low pressures. The same results for low pressures, and the same slight divergence from the general rule at high pressures, has been observed in the case of most gases. We may say, for practical purposes, however, that the volumes of all gases vary inversely as the pressure.

It is, of course, assumed that no mixture or union of the bodies in contact (mercury and air) takes place ; and also that the temperature is the same at each measurement of volume.

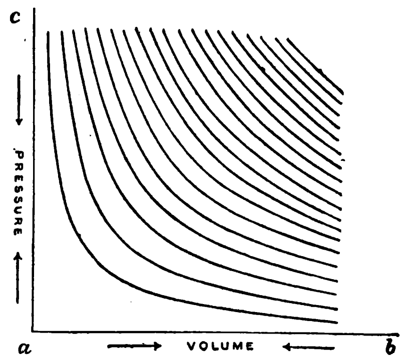


Fig. 36.

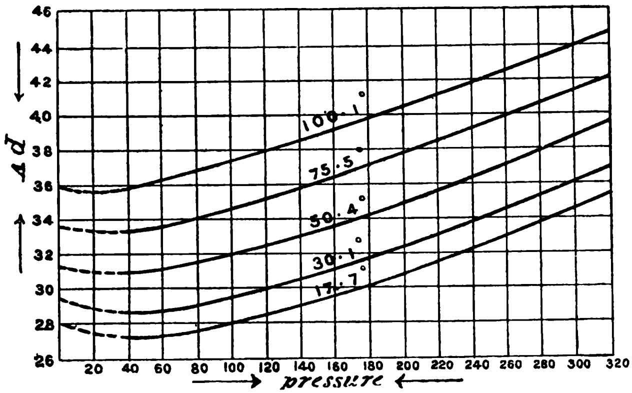
The various curves represent the relation between volume and pressure, for various temperatures, of a given gas. The vertical distances of a given point, in any of these curves, from $a\,b$ and $a\,c$, represent the magnitude of the pressure and volume respectively.

In order to measure corresponding changes we must take care in every case that these changes only are being observed, or, at any rate, we must take into account those modifications which cannot be avoided.

70. Graphic Representation of Correlative Changes by Diagram.—This mode of representing correlative changes may be illustrated by the following example :—Two straight lines $a\,b$, $a\,c$ are drawn at right angles to one another. The units of length along $a\,b$ are made to stand for units of volume, while the units of length along $a\,c$ stand for units of pressure ; that

Diagrams showing that Boyle's law is not quite true. The product of the numerical values of pressure and volume, p v, varies with pressure as shown. From Amagat's observations.

NITROGEN.



HYDROGEN.

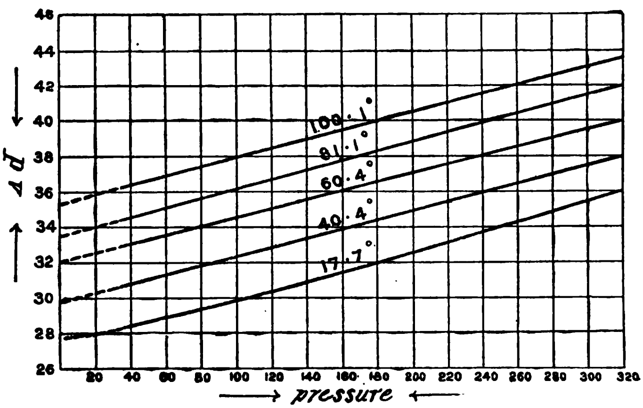


Fig. 37.

is, the magnitude of any given volume and of any given pressure is graphically represented by the magnitude of linear distance in the direction $a\,b$ and $a\,c$ respectively. The results

of a series of observations are recorded by marking along *a b* the distances corresponding with the volumes, and along *a c* the distances corresponding with the pressures, in each case according to a given scale, and then erecting at these distances perpendiculars which shall meet in points which mark by their linear distance from *a b* and *a c* the condition of the body with regard to volume and pressure at the respective observations. It is obvious that an endless number of observations would yield a continuous line instead of isolated points. Instead of this, a number sufficiently large to detect any irregularity is taken, and then the line joining the points recording these observations becomes the probably true representation of the state at all intermediate stages.

Such diagrams are given above (figs. 36, 37).

Table showing Value of Product p v for Air at Various Pressures and at Ordinary Temperatures.[1]

Pressure in Atmospheres	p v	Pressure in Atmospheres	p v
1·00	1·0000	110·82	·9830
31·67	·9880	133·51	·9905
45·92	·9832	176·17	1·0113
59·53	·9815	233·68	1·0454
73·03	·9804	282·29	1·0837
84·21	·9806	329·18	1·1197
94·94	·9814	400·05	1·1897

[1] From Amagat's observations.

71. The Measurement of the Change in Volume of a given Mass of Air, when changed from the Temperature of the Room to that of Boiling Water, while the Pressure remains Unaltered.—A round-bottomed flask is tightly fitted with an indiarubber cork, and its position in the welted neck of the flask marked. This cork is to be fitted with a short thermometer, and also with a short glass tube, to which is joined an indiarubber tube with a clip, as shown (fig. 38). The glass tube is not to project below the bottom of the cork. The capacity of the flask up to the point marked on the neck, together with

that of the tubes as far as the clip, is measured by filling with water and then emptying the water into a graduated vessel.

The flask is thoroughly dried inside, and, with the cork inserted and the clip opened, it is immersed for several minutes in a vessel of boiling water, and the temperature observed. The clip is then tightly closed and the flask quickly removed. The flask is then placed with the mouth of the tube under water of the same temperature as the room, the clip is opened, and the flask is allowed to cool to the temperature of the room. The level of the water outside is made to agree with that of the water inside the flask, and at this point the clip is closed.

The water which has entered the flask is measured by means of a graduated vessel, and, when its volume is deducted from that of the flask, we obtain the volume of air, at the temperature of the room, which will fill the flask when raised to the temperature indicated by the thermometer. This will be nearly the same as that of boiling water (100° C.). That is, we have the means of measuring the change of volume which occurs when a certain volume of air undergoes a certain change of temperature. The pressure at each temperature is the same, as it is directly exposed to the atmosphere at the higher temperature, and is brought into equilibrium with it, before measuring at the lower temperature. If accuracy is not expected, the thermometer may be dispensed with, and the higher temperature taken as 100°, but the use of a thermometer is recommended. Suitably short ones may be obtained.

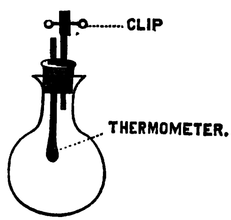


Fig. 38.

The same method may be used for other gases.

72. The Temperature-changes resulting from Changes in the Volume of Gases.—When temperature changes in gases are in question, it must be remembered that the quantity of matter constituting a given volume of gas is very small compared with that of the containing vessel. A small change of

temperature in a gas would not be easy to observe, on account of the speedy adjustment of its own temperature with that of the vessel; hence all comparisons and measurements of the changes become extremely difficult.

It is easy to show that the diminution in the pressure on a gas, with its consequent expansion, takes place together with a fall in temperature. If a thermometer is placed under the cover of an air-pump, and a portion of the air removed by means of the pump, the thermometer may easily be made to mark a fall of 8° or 10°. In this case we have a diminution of pressure on the small quantity of air remaining which enables it to expand and fill the given space. In so doing it becomes considerably colder. The same result may be shown by exhausting the air from a vessel by means of a filter-pump.

If the pressure upon a gas be increased—that is, if its volume be diminished—the temperature increases. This may be easily shown by using a force-pump to compress a large quantity of air within a given space containing a thermometer. The temperature will be found to rise just as distinctly as it fell during the converse process.

Many modifications of these experiments may be made, and they may be extended to other gases with the same results. It is of great importance to consider these results side by side with the observations that an increase in the temperature of a gas, from contact with a hot body, causes its volume to increase, provided the pressure remains the same; while a decrease in temperature causes a contraction in volume. These apparently divergent facts are reconciled if we take into consideration certain external changes, which must be considered at a later stage.

Similar results, with certain modifications, are found in dealing with liquids and solids. For example, the stretching of a wire cools it, while examples of compression causing a rise of temperature are common. Friction may be looked upon as a special case of compression. But the greater simplicity, to be subsequently demonstrated, in the structure of gases makes them easier to investigate than solids or liquids.

73. The Measurement of the Pressure of Aqueous Vapour in contact with Excess of Water at different Temperatures.—When a small quantity of water is introduced into the vacuum of a barometer, it will be found that the column of mercury is depressed through a distance which does not change on the introduction of more water, provided the temperature of the whole be unaltered. But if the temperature be caused to rise, it will be found that there is an increase of the depression of the mercury column, caused by the pressure of the water vapour; and if a temperature of 100° C. be reached, the pressure of the contained vapour would be equal to that of the atmosphere, *i.e.* the column of mercury inside be depressed to the level of the mercury outside. It will also be noticed that, if the tube itself be raised or lowered, the height of the column of mercury is unaltered. That is, the pressure of the vapour in presence of water remains the same, whatever the change in the space throughout which the pressure has to be exerted. The quantity of liquid may be noticed at the same time to diminish or increase as the space is increased or diminished. In each experiment there must be excess of water.

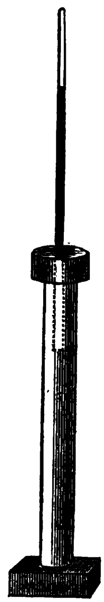


Fig 39.

Any vapour which behaves in this manner is called a *saturated vapour*. These results are independent of the presence of air, as may be shown by allowing a small quantity to enter the tube.

In conducting these experiments firm stands for the tubes are essential, and a tube with a vacuum free from water is necessary for comparison. In order to show that the pressure is independent of the space through which it is exerted, provided only there be excess of water, the cistern shown (fig. 39) is used. In order to show that the pressure of the vapour at 100° is equal to that of the atmosphere, complicated apparatus is required. What is strictly true is that water boils at that temperature at which its saturated vapour has a pressure equal to that which its surface bears. By diminishing

Pressure of Aqueous Vapour in M. M. of Mercury.

T. ° C.	M. M.	T. ° C.	M. M.	T. ° C.	M. M.	T. ° C.	Atmos.
−10	2·08	16	13·54	90	525·39	100	1·0
−9	2·26	17	14·42	95	633·69	110	1·4
−8	2·46	18	15·36	99	733·21	120	1·96
−7	2·67	19	16·35	99·1	735·85	130	2·67
−6	2·89	20	17·39	99·2	738·50	140	3·57
−5	3·13	21	18·50	99·3	741·16	150	4·7
−4	3·39	22	19·66	99·4	743·83	160	6·1
−3	3·66	23	20·89	99·5	746·50	170	7·8
−2	3·96	24	22·18	99·6	749·18	180	9·9
−1	4·27	25	23·55	99·7	751·87	190	12·4
0	4·60	26	24·99	99·8	754·57	200	15·4
1	4·94	27	26·51	99·9	757·28	210	18·8
2	5·30	28	28·10	100	760·00	220	22·9
3	5·69	29	29·78	100·1	762·73	230	27·5
4	6·10	30	31·55	100·2	765·46		
5	6·53	35	41·83	100·3	768·20		
6	7·00	40	54·91	100·4	771·95		
7	7·49	45	71·39	100·5	773·71		
8	8·02	50	91·98	100·6	776·48		
9	8·57	55	117·48	100·7	779·26		
10	9·17	60	148·79	100·8	782·04		
11	9·79	65	186·94	100·9	784·83		
12	10·46	70	233·08	101	787·59		
13	11·16	75	288·50	105	906·41		
14	11·91	80	354·62	110	1,075·37		
15	12·70	85	433·00	120	1,489·60		

Boiling-points of some Saturated Solutions.

Salt Dissolved	Quantity in 100 parts of water at Boiling-point	Boiling-point
Potassium acetate . .	800	169°
Sodium acetate . . .	209	124·4°
Ammonium nitrate . .	209	164°
Calcium nitrate . . .	362	115°
Potassium nitrate . . .	335	116°
Sodium nitrate . . .	224·8	121°
Potassium carbonate . .	205	135°
Sodium carbonate . .	48·5	104·6°
Potassium chlorate . .	61·5	104·2°
Ammonium chloride . .	89	114·2°
Barium chloride . . .	60	104·4°
Strontium chloride . .	117·5	117·8°
Calcium chloride . . .	325	179·5°
Potassium chloride . .	59·4	108·4°
Sodium chloride . . .	40·2	108·4°
Sodium phosphate . .	112·6	106·6°
Potassium tartrate . .	276·2	114·7°

the pressure upon the surface, boiling will commence at a correspondingly lower temperature.

In the same manner as above it may be shown that the saturated vapours of other liquids exert a final pressure, which is proportional to the temperature, and that the temperature at which any liquid boils is the temperature at which its saturated vapour exerts a pressure equal to that upon the free surface of the liquid.

74. The Enunciation of Avogadro's Theory.—The observation that most gases change their volume in almost exactly the same degree, when they undergo the same changes of temperature or pressure, led to the theory of Avogadro. According to this theory, similarity of behaviour is caused by similarity of structure. We must regard a given volume of a gas as a system of very small invisible particles, separated from each other by a distance which diminishes when the pressure increases or the temperature falls, and grows larger when the pressure decreases or the temperature rises. Different kinds of gases will have different kinds of particles; but equal volumes of all gases, at the same temperature and pressure, will contain the same number of particles.

The theory does not extend to the composition or structure of the particles, or to other changes consequent on a change of temperature. With these it is not concerned. It aims merely at explaining the observation that gases undergo the same change in volume when equally changed in temperature and pressure. Further investigations are necessary before the accuracy or limitation of the theory can be tested. It has the undoubted advantage of simplicity. It offers no precise explanation of the manner in which changes of volume are produced, nor of the exact condition of the system at any given moment. It assumes that a given change is effected by an average change in the distance between the particles. Some may be wider apart and some closer together than the average.

Since nothing like any heterogeneity of structure, much less isolation of particles, can ever be detected, it is indispensable to the theory that the particles must be considered as extremely small.

Avogadro's theory, then, assumes that equal volumes at the same temperature and pressure of those gases which undergo the same volume-change, when they are equally changed in temperature or pressure, contain an equal number of particles.

It is obvious, if this be true, that the relative quantities of matter contained in equal volumes of different gases under the same conditions of temperature and pressure, will be the same as the relative quantities of matter contained in separate particles of these gases. If the theory be true, we may learn the masses of relative particles which are so small as to be far removed from the possibility of direct observation.

If we admit that the observations of changes of pressure and temperature in gases lead to this conclusion, it remains to be shown how our conceptions of these changes are aided. Other observations have indicated to us that these particles are in constant motion. They must, therefore, approach the sides of the containing vessel with a frequency which is directly proportional to their number. If the volume of a system of these particles is halved, the number of their impacts on the sides of the vessel is doubled. When we speak of the pressure being doubled, this appears to be what is meant.

Again, when the temperature of a gas changes, the speed of its particles is supposed to change, an increase of speed being the real change known to us hitherto as a rise of temperature. An acceleration in the average speed of a system of particles will increase the number of impacts against the sides of the containing vessel just as much as a diminution in the capacity of the vessel. Hence, the volume remaining the same, the pressure increases with rise in temperature; or the pressure remaining the same, the volume increases.

We are driven to the conclusion that the expansion of a gas during a rise of temperature, while its pressure is unchanged, is a change of the same nature as that which occurs when a moving body, coming in contact with another body, sets that body in motion. If this be so, the converse changes which have been observed are such as might be expected. That is, the forcible diminution of the volume of a gas should cause its temperature to rise, and, using the same reasoning,

an increase in the volume should cause a fall of temperature. In the former case the speed of the particles which come in contact with the moving boundary is increased, in the latter it is diminished. The temperature-changes stated are matters of direct observation, whether the hypothesis be correct or not.

The ordinary change of temperature, consequent on contact with a body of different temperature, must be regarded, in the same way, as a change in the rate of motion of the particles through collision with particles moving at different rates. The particles from which the change is derived are not necessarily those of a gas. This explanation must be looked upon as partial only; after further investigations it may be made more complete.

It must be distinctly understood that, although all observations point to the probability of solids and liquids being made up of minute particles similar to those constituting gases, there is no reason yet adduced to suppose that Avogadro's hypothesis can be directly applied to them. The wide differences in the behaviour of various solids and liquids for the same temperature and pressure changes, would rather show that much wider investigations must be made before any theory as to their structure can be proposed. Whatever their structure may be, it is undoubtedly unlike that of gases in many respects. This is shown by the scarcely perceptible compressibility which distinguishes most solids and liquids from gases, and by the very slight trace of cohesion existing between the particles of gases. At the same time, it is important to remember that most kinds of matter may be made to pass from one state to the others by alteration of temperature, and under certain circumstances the change of state may be gradual and even imperceptible.

Additional Exercises and Questions.

1. Connect a porous earthen war vessel, such as is used for electric cells, with a thick glass tube by means of an indiarubber cork; fill the tube and vessel with coal-gas, and place it over water or mercury. Note that the quantity of gas inside diminishes until a limit is reached.

Prepare a similar apparatus, but maintain an atmosphere of coal-gas outside the porous vessel by the assistance of a vessel enclosing it, and note that a quantity of gas passes to the inside of the porous vessel. Write out a probable explanation of your observations, and suggest methods of continuing the research.

2. Ascertain by experiment the alteration of pressure produced by a given change of temperature in a quantity of air maintained at the same volume. Use a bent tube containing mercury and connect it with a flask; bring the air in the flask to its original volume by causing it to support a lengthened column of mercury.

3. Make experiments with a view to compare the physical properties of indiarubber, glass, copper, and sealing-wax. Indiarubber tubing, glass tubing or rod, and copper wire may be used. Pay special attention to elasticity, rigidity, ductility, malleability. As a result of your observations, define the properties mentioned in a more accurate and complete manner, and suggest explanations derived from the theory that matter is formed of very small particles.

4. Construct apparatus, and make observations of the amount of evaporation taking place from a liquid—water, for example—into a known quantity of air at different temperatures.

5. Show by experiment that equalisation of pressure in gases takes place rapidly, while the process of diffusion is comparatively very slow. How is this explained? Modify the apparatus of fig. 32.

6. Find out, by weighing the solid left after evaporation, the relative quantities of common salt dissolved by water at the temperature of the room, and by boiling water.

7. Prepare crystals from powdered copper sulphate. What bearing has the molecular theory of matter upon the formation of crystals?

8. How does the rate of evaporation and of solution depend upon (1) rate of diffusion and (2) temperature?

9. In what sense can one gas be said to act as a vacuum towards another?

10. Describe methods by which the rate of diffusion of gases or liquids may be determined.

11. Give a list of the chief facts which are reasonably explained by the molecular theory of matter.

12. Describe the various kinds of changes which might be expected to take place in a system of molecules if it resemble a system of visible bodies.

13. Describe some process of determining the mass of a given volume of water-vapour or steam. How will the presence of water-vapour in the air affect the height of the barometer?

14. State why the surface of mercury in a glass tube is convex while that of water is concave.

15. Make the following observations and give explanations in each case: (*a*) That mercury will not run through a fine gauze or cambric, while water does so. (*b*) That a plate, suspended by beeswax and twine from the end of a balance so that its lower surface is completely in contact with the surface of some water, will require a considerable mass to be placed in the other pan of the balance, before it is detached from the surface of the water. (*c*) That a larger mass is required in the case of mercury. (*d*) That a large globule of oil may be obtained by placing it in a mixture of water and alcohol of its own density.

16. How is evaporation distinguished from ebullition? Describe what probably takes place in each case.

17. What evidence is there that the particles of a gas, liquid, and even a solid, are in motion at ordinary temperatures?

18. Find out what alterations of volume take place when a given quantity of water, and also of alcohol, takes increasing quantities of various salts into solution.

CHAPTER VII

INVESTIGATION OF THE COMPOSITION OF VARIOUS KIND OF MATTER

75. The Separation of a Complex Body into different kinds of Matter by a Difference in Degree of Solubility in Water.— A mixture of barium sulphate and sodium chloride which is apparently homogeneous is added to water in a vessel, and stirred or warmed for some time. The liquid is now poured into another vessel, and water is freely added to the solid which remains, without any further solution, as far as can be seen, taking place. The solid suspended in the water is collected, by filtering through porous paper, and then dried upon the paper in a drying chamber. The filtrate, or liquid running through during filtration, can be rejected, but the liquid in which the mixture was first stirred is now made to evaporate in a porcelain dish. A white solid will be found to remain. We have now two solids. One of them is readily soluble in water. The other is insoluble, as may be shown by causing some water which has been in contact with it for some time to evaporate upon a watch-glass. No solid remains after the water has changed into vapour. The two solids may be set aside for future examination. The distinction so far lies solely in their solubility in water. Further distinctions will be found when they are compared under other circumstances.

A mixture of ammonium oxalate and potassium bromide is now taken, and the whole is found to completely dissolve when warmed in presence of sufficient water. The solution is made stronger by evaporation, until some of the solid begins to separate out in crystals. It is now allowed to cool, and then the liquid is poured away from the needle-shaped crystals

which form. This liquid is now made to evaporate and cool, and the liquid again poured away from the crystals formed. By repeating the process, and adding more water when necessary, we shall finally obtain a number of cubic crystals distinct in appearance from the others. The needle-shaped crystals, being less soluble in water than the cubic ones, appear more readily on a fall of temperature.

It is difficult to separate two kinds of matter which differ only slightly in solubility, and the quantities actually separated may only be a small fraction of the quantities present; but a differentiation of matter has been effected. This method, however, leads to no further differentiation of the two bodies already separated. With regard to solubility, all the parts of either body are alike.

76. The Separation of a Complex Body into Two different kinds of Matter by a Difference in their Boiling-points.—A mixture of alcohol and water, forming a homogeneous liquid, is placed in a round-bottomed flask, with a tube fitted in the cork as shown below (fig. 40). This tube is connected with a condenser, which consists of a tube passing through a thicker tube with two openings, by means of which a slow stream of cold water may be made to condense the vapour passing through the inner tube. The flask is warmed by placing it on a copper water-bath. A thermometer, fixed in the cork of the tube which is connected with the flask, shows the temperature of the vapour coming off.

As the fluid gradually rises in temperature, vapour will be perceived to come off, and collect after condensation in a vessel arranged for the purpose. The thermometer is watched, and the flame regulated, so that as much as possible of the vapour coming off at temperatures not exceeding 80° C. may be collected. When the thermometer marks a temperature above 80°, as it will when the liquid of lower boiling-point has partly passed over, the vessel for receiving the distillate is changed. When the temperature reaches nearly 100°, the distillate is again separately collected, and the distillation completed. The first portion should now be freshly distilled, and the vapour coming off at temperatures below 80° alone

collected, and the rest rejected. The last portion also is freshly distilled, and the vapour coming off below 99° C. is rejected. If necessary, this process of fractional distillation is repeated until liquids of constant boiling-point are obtained. The boiling-points are those characteristic of alcohol and water respectively. A determination of their density will also indicate that they are different kinds of matter.

A liquid which gave no indication of its complex constitution has now been resolved into two different kinds of matter, which cannot themselves be further resolved by this process.

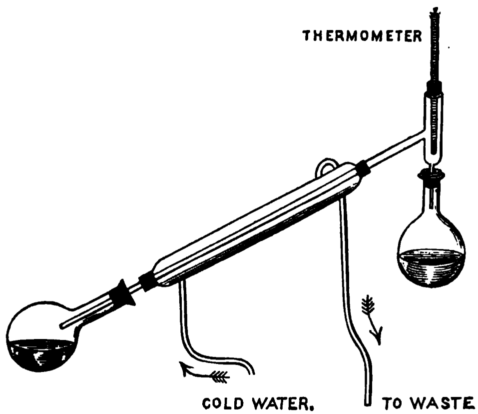


Fig. 40.

The temperature of the vapour coming from the surface of each during ebullition does not vary, except so far as the pressure of the atmosphere may vary. Each liquid is, with regard to this operation, the same in all its parts. Each liquid possesses a specific boiling-point and a specific density. So far they are distinct and individual.

77. Changes observed when Silver Nitrate is maintained at a High Temperature.—Weigh a clean dry crucible. Introduce a small quantity of pure dry silver nitrate, and weigh again. The known quantity of silver nitrate is then gently heated by

placing the crucible over a Bunsen flame. The solid liquefies, and begins to give off brown fumes. If the crucible be now removed from the flame, the change stops. It recommences as soon as it is again brought into contact with the body at a high temperature. After a time the observed change ceases, and, instead of the white crystalline silver nitrate, we have a white metal, silver. The quantity of silver is found by weighing. In order to make sure that the action is complete, the whole should be raised to a somewhat higher temperature, and again weighed after cooling. The quantity should be found the same; if not, the action was probably incomplete. The process should be repeated until the mass is constant. It may be noted that the liberated vapour diffuses into the atmosphere, and it should be remembered that the silver nitrate is exposed only to the pressure of the atmosphere while it decomposes.

Another quantity of silver nitrate is now weighed, and similarly maintained at a high temperature. The quantity of silver obtained will be found to bear the same ratio to the quantity of silver nitrate used as the quantities in the previous experiment. If further experiments are made the same definite relations will be found, provided that no change but the one in question has been going on—*i.e.* provided the required experiment has been correctly performed. We may, therefore, state that silver nitrate is probably a substance containing always a fixed proportion of silver. Fuller examination would enable us to make more exact statements about its composition. Changes of this class are called *chemical changes.*

78. Changes observable when Silver Iodate is maintained at a High Temperature.—Weigh a small quantity of pure silver iodate[1] in a weighed crucible, and gradually raise the temperature, and keep it at a moderate temperature until no further change takes place. This point is ascertained by cooling and weighing several times, until it is found that the quantity of matter remaining in the crucible is constant.

[1] Potassium chlorate may be substituted for silver iodate, which is a costly compound. The results, however, will be less satisfactory.

That a colourless gas escapes during the operation may be proved by showing that a flame becomes much brighter when held over the heated substance. It is better to try this with another portion of the substance in a test-tube. The gas is called oxygen.

The process should now be repeated with a different quantity of silver iodate. It will be found that the quantity remaining bears the same ratio in each case to the quantity taken. This will be found to hold good however many times the experiment is performed. Or we may say, that the relative quantity of oxygen contained in the substance is fixed.

The experiment itself gives no indication of the relation existing between the solid left in the crucible and the gas which has escaped. It remains to be shown that they are associated in a special manner, for which the term 'chemical combination' is used. The process described is spoken of as one of 'chemical decomposition.' It will afterwards be shown how such an association of different kinds of matter differs from a mere mixture or a solution.

We are chiefly concerned at present in noting that some substances cannot be raised in temperature beyond a certain limit without undergoing decomposition. It may be observed that the decomposition of silver iodate takes place at a lower temperature than that of silver nitrate; but in each case the temperatures are too high for direct measurement with a thermometer. We may describe these facts by saying that these two kinds of matter do not exist as such above certain temperatures. The same may be said of many other kinds of matter.

79. Modification produced when Silver Nitrate is heated within a Closed Tube.—This experiment should not be performed by students themselves, but the results are of sufficient importance to require that it should be shown to them.

A piece of thick hard glass tubing is drawn out by heating in the blow-pipe flame so as to close one end. A small quantity of silver nitrate is introduced, and the tube drawn out again so as to form a closed tube of three or four inches containing the silver nitrate (fig. 41). The glass should be

heated gradually, and allowed to cool gradually, lest it be weakened in the process.

The tube is then placed over a small Bunsen flame, and shielded to ensure safety from possible danger of the tube breaking. The enclosed solid liquefies as before, and commences

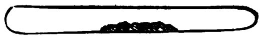


Fig. 41.

after a time to give off a dark-red vapour, which fills the tube. It may remain for some time at a temperature much higher than that at which it is completely decomposed, when the vapour escaped into the air. The flame is removed and the tube allowed to cool. The vapour will be noticed to apparently diminish in quantity from the colour becoming much lighter. On breaking the tube, a small quantity only of vapour escapes; and an examination of the solid in the tube shows very little trace of silver. If the solid is again placed in the flame, with free outlet, the decomposition rapidly proceeds, and silver is readily obtained. Similar results may be obtained by using other substances, and we learn that chemical changes do not depend on temperature alone. The precise alteration produced by this change of conditions has not been shown by this experiment, which merely indicates the necessity of studying every aspect of the system undergoing change. In the first case the vapour contained in the silver nitrate was free to diffuse away into the air; in the second case it was confined to a small space, unable to escape, although undoubtedly exercising, together with the air, so great a pressure upon the inside of the tube as to make it liable to burst. The results have been very different. Further investigations would be required to show the exact nature and extent of the modifications of which this is an illustration.

An important observation, resembling the one just described, may be made by placing some zinc, magnesium, or similar body in a specially thick tube to which a good cork has been carefully fitted. Dilute acid is added, and the cork replaced so

that no gas escapes. The evolution of gas will cease after a time, but will continue again if the cork is removed. The presence of a relatively large quantity of the gas in the confined space evidently prevents further action. It is advisable not to cork the tube when the action is very rapid, and to watch the tube, when corked, from some distance.

80. Decomposition takes place when Silver Nitrate, or Similar Bodies, either Liquefied or in Solution, forms part of an Electric Circuit.—Some silver nitrate is dissolved in pure water, and, when placed in a suitable vessel, made to form part of an electric circuit. Connection with the circuit is made by hanging in the solution two copper plates, of which the weights have been taken, and attaching them, as shown (fig. 42), to the wires leading to the cells, by means of hooks and binding-screws fixed in a wooden support. Plates are used in order that the portion of the solution added to the circuit may have a large sectional area.

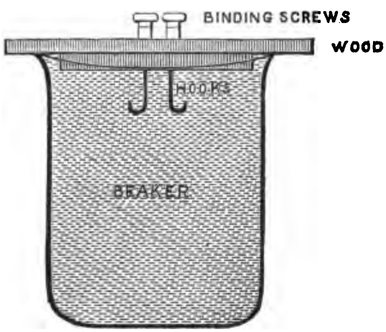


Fig. 42.

It has been shown that conductors of small sectional area diminish the stress of the circuit.

After a few minutes it will be found that one of the copper plates has become coated with a white metal, which is evidently silver. On carefully drying and weighing this plate it will be found heavier.

Some silver nitrate is raised in temperature so as to liquefy without being decomposed, and then connected with the circuit by two wires dipping into it. After a short time a bead of silver will be found at the end of one of the wires. If solid silver nitrate is used no decomposition takes place. The liquid condition is essential to electric decomposition or electrolysis. If a solution of copper sulphate is substituted for that of silver nitrate in the first experiment, a similar change will be

observed; one of the copper plates will become heavier by deposition upon it of copper. The other plate, however, will be found to be correspondingly lighter. We are thus led to investigate the other plate used in the case of silver nitrate. This will be found lighter, but not correspondingly lighter.

In order to obtain accurate results the quantities measured should be as large as possible. This may be effected by increasing the number of cells, or allowing the change to proceed for a longer time.

It will be noticed that the change in question appears to take place at the places of contact between the solution and the rest of the circuit. It is, however, difficult to understand how these regions can be alone affected, for we have no reason to suppose any one portion of the liquid between the plates to differ from another with regard to its electric condition. There is apparently, therefore, an internal change set up throughout the liquid which is in the circuit, but this change is only manifested at the places where it starts and ends. The result is as if the particles of the solid in solution had been decomposed, and the products directed or arranged in a special manner. That the copper added to the heavier plate is derived evidently from the solution, and not, as might appear, from the plate which has lost matter, may be proved by using platinum or silver plates instead of copper. The deposition of copper proceeds in much the same manner as before.

81. The Quantity of a given kind of Matter, liberated under the same Electric Conditions, is independent of the kind of Matter associated with it; while the Quantities of Different kinds of Matter, liberated under the same Electric Conditions, have a fixed Invariable Ratio to one another.—Solutions of copper sulphate, copper nitrate, and silver nitrate are placed in an electric circuit. Clean copper plates are used as before for making connections, except with the silver nitrate solution, into which silver plates dip. Each of the plates is carefully weighed and marked. It is convenient to use in these experiments a key, by which the circuit can be closed or opened at will. While the necessary connections are being made it remains open. We may then submit the three

solutions to the same conditions for any length of time. The plates are then detached, dried, and weighed. It will be found :

1. That one of the plates in each solution has increased in mass, while the other has decreased to the same extent. The one which increases has always the same relative position in the circuit.

2. That the quantity of copper so acted upon is the same in the solutions of copper sulphate and copper nitrate.

3. That the quantity of silver affected differs from that of copper, and bears to it the ratio of 108 to 31·5. A repetition of the experiment will show that the relation between the quantities of silver and copper is maintained. By including other solutions in the circuit, the relative quantities of other substances liberated may be obtained.

The gain in the mass of one plate, coinciding with an equivalent loss from the other, would indicate that there is a transference of material from one plate to the other. By substituting platinum plates, however, it may be shown that this is not so ; for then an increase alone takes place, the other plate not diminishing in mass. It is probable, therefore, that the loss of material from one of the plates is a secondary change, due to the solvent action of the altered liquid upon it. It becomes a matter of further investigation why the quantities should in this case be equal. The explanation will be found to lie in the mutual relations of the constituents of the substance decomposed.

It may be noticed here that the electric circuit gives an opportunity of submitting several bodies simultaneously to exactly the same conditions relatively to electric stress. Whatever variation there may be in various portions of the circuit, and however varied may be the changes going on, there is the same electric stress throughout.

82. Decomposition of a Body by Close Contact with another Body.—Formation of new kinds of Matter when Two Bodies react Chemically.—A piece of zinc is added to some dilute hydrogen sulphate. It dissolves, while bubbles of gas come off, and the temperature of the liquid rises. If the

change is one of ordinary solution, the zinc may be recovered by causing the liquid to evaporate. This is now done, but instead of zinc we obtain a white crystalline body. By using a double-necked vessel, fitted with a thistle tube, for adding the hydrogen sulphate after the zinc has been placed in the bottle, and a delivery tube, a quantity of the gas may be prepared and collected over water. It will be found a very light and inflammable gas. By substituting a narrowed tube for the delivery tube, and taking every precaution that the issuing gas is not mixed with air, it may be made to burn with a steady blue flame. A cold clean glass vessel held over the flame will become moist, as if steam had condensed upon its surface. The gas is called hydrogen. We have therefore obtained, by the interaction of zinc and hydrogen sulphate, two new kinds of matter.

The rise of temperature which coincides with the above changes cannot yet be explained. Some definite thermal change will always be observed when a chemical change takes place. Besides this, however, there are other conditions, which are never absent from this kind of change.

Definite quantities only of the reacting bodies are concerned in the change. In a case of ordinary solution there may be more or less of a solid dissolved, provided a certain maximum quantity be not exceeded; but there is no such variety possible in this case. If a large quantity of zinc is added to a small quantity of hydrogen sulphate, most of the zinc will be unchanged. It may be recovered and proved to be unaltered. Some, however, has reacted with the liquid, as may be shown by evaporation. On the other hand, if excess of hydrogen sulphate is used, unchanged hydrogen sulphate will be found after the action is completed. This may be proved by using the distillation apparatus, and showing that the distillate retains its power of changing the colour of litmus—a power which entirely disappears when excess of zinc is used.

It will be noticed that in this and in nearly every similar case of chemical change, one or more of the reacting bodies must be in the liquid or gaseous state. It might be supposed

from this fact that a peculiar closeness of contact is necessary before chemical change can occur; a supposition which is strengthened by all chemical research, and especially by the fact that solids, which may exist without change side by side, even when finely divided, for any length of time, may be induced by great pressure to combine chemically.

83. Chemical Combination always takes place between Definite Quantities; consequently each Elementary Substance has a Specific Value in Chemical Exchange.—The element magnesium, when placed in a solution of silver nitrate, is dissolved, and at the same time the element silver is precipitated. If a known quantity of magnesium is added to silver nitrate, sufficient in quantity to completely dissolve it, the quantity of silver precipitated will always be found to have the same ratio to the quantity of magnesium taken.

In the same way the element iron is dissolved by a solution of copper sulphate, while the element copper is simultaneously precipitated. For the same quantity of iron dissolved, the same quantity of copper is always precipitated.

Similar observations may be made with other substances, and it will be always found that definite invariable quantities of various elements are, in cases of chemical action, equivalent to one another. The relation existing between the quantities taking part in the same chemical change never varies. A given compound is always formed of the same constituents united in the same relative quantities, whatever may have been the conditions under which it was formed.

Weigh a porcelain crucible, and add some pure magnesium in small pieces of ribbon, and weigh again. Add to the known quantity of magnesium in the crucible a quantity of silver nitrate solution, sufficient to react completely with the quantity of magnesium present. Preliminary experiments will have indicated the quantity needed. Constant stirring with a short glass rod is advisable. The temperature of the solution will be noticed to rise during the reaction. After the magnesium has disappeared the solution is gently heated. The silver, which has been precipitated, is separated from the excess of silver nitrate by decanting through a filter and

repeating the process, after the addition of water, a sufficient number of times. The silver is thus washed, and if time be allowed for settling before each decantation, none need pass to the filter paper. If it does, it may be made to return to the crucible by a stream of water, or by burning the dried paper over the crucible. The silver in the crucible is now carefully dried, and finally raised to a red heat; it is then cooled and weighed.

In much the same way the equivalent quantities of iron and copper are determined. A small quantity of pure iron wire is weighed in a porcelain crucible of known mass. Add to this a warm solution of copper sulphate. After they have been in contact for some time, break up the copper with a glass rod, so that any unchanged portion of the iron may come in contact with the solution, and then warm gently. The copper which is formed is washed by the addition of water and frequent decantation. It is then dried carefully over a water-bath, as it undergoes change when raised to a high temperature in the air. The crucible is then dried and weighed.

84. The Relative Quantities of Chemically Reacting Matter.—Equal Quantities of Magnesium and Aluminium set free from Hydrogen Sulphate different Volumes of Gas at the same Temperature and Pressure; but there is a Constant Ratio between these Volumes, and this Ratio is maintained when the Gas is liberated from Hydrogen Chloride. A small quantity of magnesium is weighed, and a mass of aluminium is made equal to it. Two graduated tubes are filled with water, and supported in a vessel of water. The equal quantities of the two metals are placed at the bottom of the vessel, directly under the tubes, which are then brought very near to the bottom of the vessel. Hydrogen sulphate is now added, and by diffusion through the water it reaches the metals. Gas is observed to be liberated. If the quantity is too great to be collected in the tubes, smaller quantities of the magnesium and aluminium will need to be taken. Before measuring the relative volumes of the gas, it is necessary that they should be in exactly the same condition. They will be in the same condition with regard to temperatures, and will

consequently contain the same amount of water or hydrogen sulphate vapour; but they are evidently not in the same condition with regard to pressure. To remedy this the tubes should be raised or lowered, in another vessel if necessary, until the gas is in each case counterbalancing the pressure of the atmosphere.

If the pressure of the atmosphere be now read from the barometer, and the temperature be taken, the volumes of the gas, now found to correspond with the known quantities of the metals, may be subsequently utilised. So far, we are only concerned with the difference which is shown in the extent of the action of different kinds of matter upon hydrogen sulphate. When other equal quantities are taken, the same ratio is maintained in the volumes of gas liberated.

The gas which is set free in each of the tubes may be shown to be inflammable. That it is the same gas we have not yet proved, although a little research would be sufficient to prove this.

The same operation may be carried out with the substitution of hydrogen

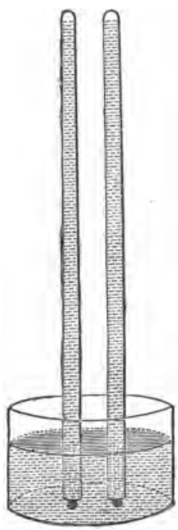


Fig. 43.

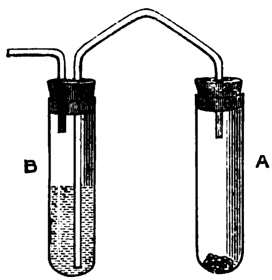


Fig. 44.

chloride for hydrogen sulphate, and the same observations may be made. The ratio which is observed in one reaction is maintained in another.

We have now observed another example of decomposition taking place through contact with another kind of matter. Both hydrogen sulphate and hydrogen chloride have been decomposed by contact with magnesium and also by contact with aluminium.

That different quantities as well as different volumes of the gas are set free may be proved by using the apparatus illustrated (fig. 44). A known quantity of the metal is placed in the tube A, while the tube B contains the liquid. The whole is then weighed by suspending it with thin wire from the hook of the pan. Air is now gently blown from bellows into B, so that a portion of the liquid passes over into A, whereupon gas escapes through the liquid in B. When the change is complete, weigh again. The apparatus should be constructed of the lightest material, or the loss will be a very minute fraction of the whole quantity, and the corks must fit perfectly air-tight and, for safety, be coated with paraffin. It must not be forgotten that in this case, and in all similar cases, no account is taken of the gas which remains dissolved in the liquid. Some gases might be dissolved in large quantity. Also we are dependent on the purity of the bodies used.

85. The Relative Quantities of Chemically Reacting Matter. The Relative Quantities of Silver Nitrate and Sodium Chloride chemically reacting always the same.—A known quantity of pure dry sodium chloride is dissolved in a known quantity of water; a known quantity of pure silver nitrate is likewise dissolved in a known quantity of water. Graduated vessels are used for the purpose. A known fraction, which should be small, of the silver nitrate solution is placed in a beaker; and a graduated burette is filled with some of the sodium chloride. The sodium chloride is then added gradually, until the white precipitate which is at first given ceases to appear. In order to know when this stage is reached, great care is needed. The liquid is boiled and stirred for some time. On account of this, the precipitate collects together and sinks to the bottom; and any further precipitate is readily seen in the clear liquid above. By making several preliminary experiments, the approximate quantity of sodium chloride solution

required to give the maximum quantity of precipitate is ascertained. We ought, in fact, to proceed so as to obtain at each operation narrower limits. Care is needed in reading the height of the column of the solution which is in the burette.

It will be found that equal quantities of the silver nitrate solution require equal quantities of the sodium chloride solution. Measurements must be made accurately, and under the same conditions. Equal quantities of the same solution, however, contain equal quantities of the dissolved substance, as has been shown by observations of diffusion.

In addition to this proof of the equality of the reacting quantities, we have an indirect one in the fact that the quantities of precipitate are exactly equal when equal quantities of solution are used. The precipitates given in two of the previous operations are separated, by filtration through papers of which the weights have been taken after drying; washed with water, to remove from them any other kind of matter, and then thoroughly dried. The quantities thus measured will be found to be equal. It is easy to calculate, from the method adopted, the relative quantities of silver nitrate and sodium chloride which react with one another.

It has been taken for granted in this operation that the precipitate yielded by the reacting bodies is insoluble in water. This may be shown to be true in the manner previously described. It has also been taken for granted that the cessation of the precipitation marks the end of the chemical change in question; or, in other words, that the addition of further quantities of the one or the other reagent is followed by no further change. It is present, as any other inert body might be, in an unaltered condition. This may be proved by those processes of fractional distillation and solidification which have been already described, or by further chemical investigations.

86. Some Conditions of Chemical Change.—Two kinds of Complexity of Matter.—We have learnt that a complex body may be separated into parts by making use of any difference in the physical properties of these parts. For example, a difference of solubility in water allows us to separate a more

soluble body from one less soluble, even when they are so associated as to be indistinguishable in other ways. In a similar manner, a substance may be shown to contain more than one kind of matter by reason of its parts having different boiling-points. Investigation must take many directions before we are satisfied that a given substance is homogeneous and individual. We have learnt also that a body may exhibit another kind of complexity; for a body which cannot be resolved into dissimilar parts by some processes may yet yield to others. For example, a body, perfectly homogeneous in some respects, may be decomposed when raised sufficiently in temperature, or when forming part of an electric circuit, or when placed in contact with other substances. Such bodies are called 'chemical compounds,' and are distinguished from other complex bodies by the fact that the same body contains always the same relative quantity of each component. When the process of analysis has been carried to its extreme limit, and when specimens of matter from all portions of the earth's surface have been subjected to the test, it has been found, so far, that there are over seventy different kinds of matter which resist further decomposition. These are called 'elements'; and their different modes of combination with one another give rise to that great variety which the surface of the earth presents to our senses. It must be remembered, however, that fresh investigations are always leading to new knowledge, and the future may show that there are more elements; while, on the other hand, it may show that there are fewer, by proving that our elements are really compounds of a smaller group of more elementary substances. It must also be remembered that the distinction between chemical compounds and ordinary mixtures is one which must not be adhered to without discretion. Although very serviceable in preliminary classification, it will have to give way when we come to investigate a large number of bodies which belong partly to one class and partly to the other. The nature of alloys, the considerable change of property in large masses produced by slight admixtures, the nature of many vegetable and animal products, all seem to show that there are relationships between different

kinds of matter which cannot be exactly included in either class, and that our theories of elements and chemical combination may need modification.

Table of Commoner Elements.

Elements	Symbols	Equivalents	Probable Atomic Masses
Aluminium	Al	13·75	27
Antimony	Sb	122	119·6
Arsenic	As	75	75
Barium	Ba	68	137
Bismuth	Bi	210	207·5
Boron	B	11	10·9
Bromine	Br	80	79·8
Cadmium	Cd	56	111·7
Calcium	Ca	20	40
Carbon	C	6	12
Chlorine	Cl	35·5	35·4
Chromium	Cr	26·3	52
Cobalt	Co	29·5	58·7
Copper	Cu	31·75	63·3
Fluorine	F	19	19
Gold	Au	98·5	196·6
Iodine	I	127	126·5
Iron	Fe	28	55·9
Lead	Pb	103·5	206·4
Lithium	Li	7	7
Magnesium	Mg	12	24
Manganese	Mn	27·5	54·8
Mercury	Hg	100	200
Molybdenum	Mo	48	96
Nickel	Ni	29·5	58·6
Nitrogen	N	14	14
Oxygen	O	8	16
Phosphorus	P	31	31
Platinum	Pt	98·5	194·4
Potassium	K	39·1	39·1
Silicon	Si	14	28
Silver	Ag	108	107·7
Sodium	Na	23	23
Strontium	Sr	43·75	87·5
Sulphur	S	16	32
Thallium	Tl	204	203·7
Tin	Sn	59	118
Titanium	Ti	25	50
Tungsten	W	92	183·6
Uranium	U	60	239
Vanadium	V	51·4	51·2
Zinc	Zn	32·5	65

87. Measurement of the Mass of a Litre of Air.—A round-bottomed flask, of about half a litre capacity, has a caoutchouc cork carefully fitted, and its position marked on the neck of the flask. This cork is provided with a short glass tube, passing just to the bottom of the cork, and continued above in a short caoutchouc tube on which is fixed a clip. The capacity of the flask to the mark, together with that of the short tube, is taken by measuring in a graduated vessel the water which fills them. A small quantity of water is then poured into the flask, and the cork carefully fitted to the mark ; the clip is opened, and the water carefully boiled for a few minutes, until the steam formed has swept out all the air. The clip is closed, and the flame simultaneously removed. The flask with water, &c., is now weighed. Then the clip is opened, and the flask allowed to cool to the temperature of the room, and then again weighed. The increase of weight shows the mass of air entering. The volume of air entering is given by subtracting the volume of water still remaining in the flask from the total volume originally ascertained.

The mass of a given volume of air may also be measured by the following process :—A round-bottomed flask, fitted as in the previous determination, is weighed together with the air it contains. It is then exhausted as completely as possible by an air-pump, filter-pump, or the mouth, the clip closed, and the mass again taken. The mass now found represents the flask and a small remnant of air. By opening the clip under water, allowing the water to enter, adjusting the water-level inside to that outside, and closing the clip, the volume of the exhausted air is easily determined.

Neither of the above determinations, however, do more than give the mass of a certain volume of air, at a certain temperature and pressure, mixed with more or less water-vapour. The density of the air varies with temperature and pressure in a manner which has been shown. The thermometer and barometer readings will indicate the corrections to be made. The quantity of water-vapour present has been shown to depend upon the temperature. By consulting the table on page110, the proportion of water-vapour present at the time

of observation may be found. A litre contains 1,000 cubic centimetres. All the necessary data are now ready for calculation.

88. The Measurement of the Quantity of Oxygen evolved by heating a given Quantity of Silver Iodate, and also of the Density of Oxygen.—A weighed quantity of silver iodate is heated in a small tube A of hard glass, connected with a vessel as shown below. As the oxygen is evolved, it displaces from the vessel B a corresponding volume of water, which is collected in a graduated vessel C. The loss of matter from A, when the change is complete, gives the quantity of oxygen previously contained, and also the weight of oxygen contained in a measurable volume.

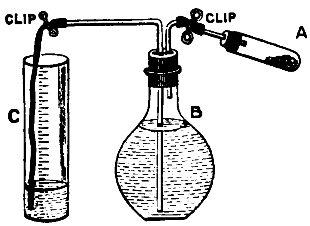


Fig. 45.

The corks must fit the tubes and vessels so as to be perfectly air-tight. The tube must be gradually raised in temperature by a Bunsen flame, allowed to remain at a moderate temperature for some minutes, and then allowed to cool to the temperature of the room. The water in the graduated vessel is brought to the same level as that in the aspirator. We know then that the pressure within the apparatus is the same as that of the atmosphere, which may be ascertained from the barometer. The volume of water in the graduated vessel will equal the volume of gas given off from A. Its temperature and pressure are known, and the quantity of water-vapour which will be mixed with it at the observed temperature is given in the table on page 110. The loss of matter found from weighing A will be equal to the quantity of matter contained in this volume of gas, and hence the density may be found.

The density may also be measured by means of the atmospheric pressure forcing back the oxygen from the vessel B into a vacuous flask which has been put in the place of A. From this flask all the air has been expelled by steam, as described in the previous experiment, and it has been accurately weighed. It is connected with the vessel B, and the

clip slowly opened. At the same time the vessel C is raised, so that the water in it may be at the same level as that in the aspirator. We have now the flask filled with oxygen and water-vapour, at a pressure of the atmosphere which is read by the barometer, and at a temperature which is made to agree with that of the room. The proportion of water-vapour for this temperature is ascertained; the flask is again weighed. The increase of mass represents a certain volume of oxygen, which is found by subtracting the volume of water from the whole volume of the flask, and making allowance for the water-vapour present. The density thus found should agree with that found by the former calculations.

It may be noted that inaccuracy will be caused by the small quantity of air which is in the tube A and the connecting tube at the commencement of the operation. For this reason they should be as small as possible.

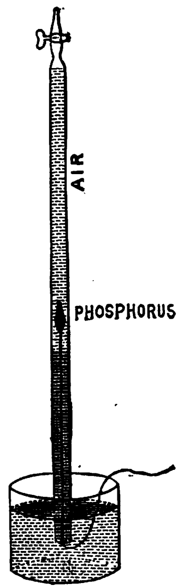


Fig. 46.

89. Analysis of Air by means of Phosphorus.—A long graduated tube, with a tap and nozzle at one end, is held upright, with its open end under the level of water in a vessel. An inverted burette answers the purpose (fig. 46.) The level of the water inside is made to agree with that outside the tube, and then accurately read. A piece of phosphorus, attached to the end of a copper wire, is then pushed up about half-way inside the tube. The phosphorus is allowed to remain as long as the water rises within the tube—an action which will continue for a day or more. It is then removed. The pressure within the tube is again adjusted to that of the atmosphere, and the volume of gas remaining is ascertained. This space will be filled by that portion of the air which is not acted upon by phosphorus and by water-vapour, the proportion of which may be ascertained from the table on page 110.

The nature of the residual gas remains to be proved. It is called nitrogen. The gas which has been removed is oxygen, as may be proved afterwards. The density of the residual gas may be found by the method previously used. A weighed flask, containing only a small quantity of water, and of suitable capacity for the burette, is connected with the nozzle. The tap is turned, and then the clip slowly opened. The nitrogen will enter the flask. The calculations, correcting for temperature, pressure, and water-vapour, are the same as before.

The density of nitrogen now being known, as well as that of oxygen, it is easy to calculate what would be the density of a mixture of these gases in the proportion by volume observed for air. The result of this calculation should be compared with the observed density of air. They should be found to agree, and afford a reason for supposing the air to be a mixture of oxygen and nitrogen. We have no reason, however, for supposing that this is the exact truth. These experiments cannot be expected to yield anything more than approximate results. Far more delicate investigations are needed to prove the exact composition of air. As far as we know, there may be still some further differentiation possible, although the proportion in which other substances may be present must be small, as is indicated by the close agreement of the calculated density with that which has been observed.

90. Some Effects of the Atmosphere.—The earth is completely enveloped by the atmosphere. The atmosphere or air is therefore present during all natural changes taking place on the surface of the earth; and in many of them it is an essential agent.

Oxygen is withdrawn from the air, and combines with other matter, in many frequent changes. This combination may take place gradually, as in the case of phosphorus, which has been already described, or rapidly, as when combustible matter burns. Those complex changes which constitute growth and decay can only go on in the air. They are conditional on its composition, *i.e.* the composition of the air

determines what the changes shall be. The changes chiefly associated with the life of animals are those in which oxygen, after diffusing into the blood through the lungs, forms, with a portion of the blood, a chemical compound, which then diffuses outwards. Inspired air differs from that which is expired, as may be shown by the use of a solution of calcium oxide.

In addition to the influence of the atmosphere in this direction, it has an important bearing upon all thermal changes in helping to bring about thermal equilibrium. Whenever a change in the temperature of a body is produced by any other change, there is soon a restoration of thermal equilibrium between it and neighbouring bodies. In this process the air is very active. By special appliances it may be retarded sometimes.

We may add to this the very important function of the atmosphere in bearing away gaseous products from a region of chemical change. The nature, as well as the extent, of many chemical changes are determined by the dissipation of some of the products of the change. By this means an action may be extended, or even changed in character; but probably the latter result is likewise due to thermal equilibrium rapidly occurring among gaseous particles. When a chemical change takes place under altered pressure, we need to consider how far it is likely to be affected by such conditions as those given above.

Water-vapour, which is always necessarily present in the air, is undoubtedly active in many natural changes. It has been shown that in dry air fewer substances burn than in moist air. Experiments, however, are difficult in this direction; but the value of our present results is not diminished so long as we remember that all the substances present in a given change should be recorded, even when they appear insignificant. It is of primary importance that we should bring all these considerations of pressure, mass, temperature, and diffusion, together with others, to bear upon the investigation of all changes, even those which appear, or have been regarded as, simple.

91. Changes observable when the Temperature of Copper Oxide is raised in a Current of Hydrogen or Coal-gas.— Heat some bright copper filings, in an open vessel, to a high temperature, and they become dark-coloured. This change, however, is likely to be incomplete, the dark-coloured substance coating some still unchanged copper. Chemical changes in which solids are engaged are, from the nature of solid matter, unlikely to be extended to the whole of the matter, unless the products of the change are removed from the region of chemical activity by means of the process of diffusion.

This substance may, however, be prepared otherwise than by raising the temperature of copper in the presence of oxygen. Place some of this pure prepared copper oxide in a tube of hard glass, which is closed at one end, and has been carefully weighed. Dry the tube and oxide by slightly heating them, so that the water condensed on their surface may be gasified; then place the tube in a vessel of which the air is kept free from water-vapour by strong hydrogen sulphate, which absorbs all the water in its neighbourhood, and allow it to cool. Such an arrangement is called a desiccator, and may be made by placing a shallow vessel of hydrogen sulphate on ground glass, and covering with a bell-jar with ground edges. The object to be kept dry should be supported over the hydrogen sulphate. The tube is then carefully weighed, supported slantingly, and kept filled with coal-gas by means of a caoutchouc tube which is connected at one end with the gas supply or a supply of hydrogen, and at the other with a glass tube of which the end has been drawn out. This tube passes through a cork, which is very loosely fitted in the tube containing the copper oxide. By this means the air may be excluded from the tube while it is being heated by a Bunsen flame. It has been shown that copper at a high temperature unites with the oxygen of the air. Copper oxide itself is therefore unlikely to be changed when heated in the air, and this is easily demonstrated. But now that hydrogen (or its substitute, coal-gas), instead of air, is in contact with the oxide, a change is soon visible. A vapour condenses at the top of the tube, and finally disappears as the heating continues.

The flame is now removed, and the tube and contents cooled, while the air is still excluded. Copper will now be seen in the place of the copper oxide. It is again slightly warmed, and at once placed in the desiccator to cool, and afterwards weighed. We have now all the data which are needed for determining the quantity of copper in a known quantity of copper oxide.

It is evident that we are assuming in this experiment

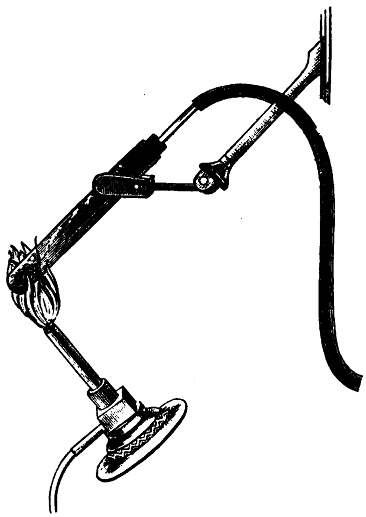


Fig. 47.

both the purity of the copper oxide and the identity of the red substance with copper.

92. Copper Oxide is caused to yield up its Oxygen when it is raised in Temperature and a Stream of Hydrogen is passed over it. The Hydrogen and Oxygen under these Conditions combine chemically and form Water. The Water is Collected and Weighed.—In the previous experiment attention was only directed to the quantity of copper contained in a given quantity of copper oxide. In the following

experiment we trace the course of the oxygen leaving the copper, and learn the relative quantities of oxygen and hydrogen which unite under these circumstances and form water. In order to do this it is necessary to collect and weigh all the water which is formed, and measure the loss of weight sustained by the copper oxide. This is carried on in the following experiment :—

A tube A of hard glass is partly filled with copper oxide, and connected at one end with the supply of hydrogen B and C, and at the other with the tube D which collects the water formed. Before making the connection, the tube containing the copper oxide is dried carefully and weighed, and the tube D, which is filled with calcium chloride or phosphorus

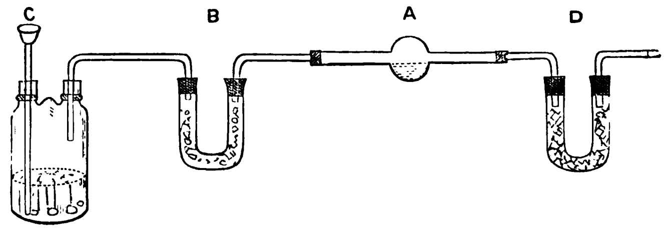


Fig. 48.

pentoxide, is also weighed. The ends of the tube are temporarily closed, so that it does not abstract water vapour from the air, during and after the operation of weighing. After connecting together the parts of the apparatus, hydrogen is prepared, by adding dilute hydrogen sulphate to the zinc contained in the vessel C. The hydrogen leaving this vessel is mixed with water vapour until it is dried by coming in contact with calcium chloride or other drying substance placed in the tube B.

The copper oxide is now heated by a suitable flame, and kept for some time at a low red heat. The temperature of the tube is now allowed to fall, while hydrogen continues to pass through it. It is weighed when cold. The loss of matter is due to the oxygen, which has combined with some of the

hydrogen coming in contact with it. The tube D is also weighed, with the same precaution as before, and the increase of mass is due to the water which has been formed by the union of the oxygen and hydrogen. The relative quantity of hydrogen, entering into the composition of water, is indirectly denoted by the difference between the quantity of water formed and the quantity of oxygen yielded up by the copper oxide.

In this experiment we assume that the hydrogen is pure; that the matter taken away from the copper oxide is oxygen; and that this oxygen is afterwards retained wholly in the tube D in combination with hydrogen.

93. Different Relative Quantities of the same kinds of Matter may combine Chemically.—In describing the law of definite proportions, it is important to state that the same relative quantities of constituents are only to be found in the same compound, since different compounds may be formed of precisely the same kinds of matter. It remains to be shown under what circumstances the same kinds of matter may combine chemically, and produce compounds differing in properties. We may take, as an example, two compounds of lead and oxygen, lead monoxide and lead dioxide.

In precisely the same manner as copper oxide was analysed, by raising its temperature in the presence of hydrogen, lead monoxide and lead dioxide may now be analysed, and the relative quantities of their constituents found. We observe that, in the lead dioxide, there is double the relative quantity of oxygen that there is in the lead monoxide. In all other examples that are examined, it will be found that the relative quantities of the constituents in one compound are related in a simple manner to the relative quantities of the same constituents when they happen to form another distinct compound.

These two compounds are considered as different kinds of matter for the following reasons: they differ in appearance (one is yellow, the other dark brown); their densities are unlike; their behaviour when placed in contact with other bodies is not the same (their chemical behaviour differs).

The most striking examples that can be given of this law

of chemical combination, which has been called the law of combination in multiple proportions, will be found among compounds containing carbon. The following table gives a number of distinct compounds, containing only carbon and hydrogen. The relative quantities of these elements in each compound vary in the manner indicated. The Atomic Theory will be found to give a reasonable explanation of these relations, and also of the formulæ by which the different kinds of matter are denoted. The distinctness of the substances is indicated by the difference in such physical properties as density, melting-point, and boiling-point.

Table of Homologous Paraffins.

Bodies containing Carbon and Hydrogen united in different Relative Quantities.

Name	Formula	Boiling-Point	Density	Relative Quantities of Carbon and Hydrogen
Methane	CH_4	—	—	3 : 1
Ethane	C_2H_6	—	—	4 : 1
Propane	C_3H_8	—	—	4·5 : 1
Tetrane	C_4H_{10}	1°	·600	4·8 : 1
Pentane	C_5H_{12}	38°	·636 at 17°	5 : 1
Hexane	C_6H_{14}	71°	·676 at 0°	5·142 : 1
Heptane	C_7H_{16}	99°	·699 at 15°	5·25 : 1
Octane	C_8H_{18}	124°	·703 at 17°	5·333 : 1
Nonane	C_9H_{20}	148°	·728 at 13·5°	5·4 : 1
Decane	$C_{10}H_{22}$	166–168°	·739 at 13·5°	5·454 : 1
Endecane	$C_{11}H_{24}$	180–184°	·765 at 16°	5·5 : 1
Dodecane	$C_{12}H_{26}$	202°	·774 at 17°	5·538 : 1
Tridecane	$C_{13}H_{28}$	216–218°	·792 at 20°	5·571 : 1
Tetradecane	$C_{14}H_{30}$	236–240°	—	5·6 : 1
Pentadecane	$C_{15}H_{32}$	258–262°	·825 at 16°	5·625 : 1
Etc.				Etc.

94. The Rise in Temperature during Chemical Combination.—A quantity of sulphur is allowed to burn in oxygen and form sulphur dioxide. The sulphur dioxide thus formed is at a temperature much higher than that of the sulphur or oxygen. The magnitude of this thermal change is approximately measured by the change in temperature of a known quantity

of water surrounding the vessel in which the chemical change takes place. The sulphur dioxide which is formed is, at ordinary temperatures, a gas. The temperature of the sulphur dioxide, when formed from its constituents, is always the same. This is shown by the same quantities of sulphur and oxygen always producing, on combination, the same thermal change in the neighbouring body, water.

The experiment may be roughly carried out in the following manner: A vessel (A) is fitted with a cork containing three holes. In one of these is fixed a tube conveying the oxygen; in another a long tube of thin copper, which is coiled several

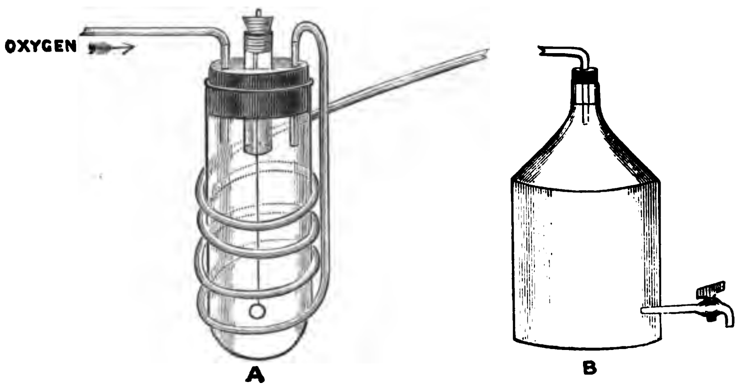


Fig. 49.

times round the flask. This serves to carry away the sulphur dioxide as it is formed, and bring about thermal equilibrium between it and the water. It finally enters the aspirator B, by which a slow stream of air or oxygen is drawn through the vessel A. The third opening, in the centre, serves to introduce the sulphur immediately the action is started, or this may be done by touching the already fixed sulphur with a hot wire. The oxygen used may be pure, or mixed with nitrogen, *i.e.* air may be used. The numerical results will differ accordingly; but, in any case, the same quantity of sulphur, uniting with oxygen under precisely the same conditions, will produce the

same thermal change in the water. We may therefore say that the compound formed is always at the same temperature under the same conditions.

If phosphorus be substituted for sulphur in the above experiment, the numerical results will be found to differ. An increase of temperature is observed in the water, and for the same quantity of phosphorus, under the same conditions, the increase is always the same, but it differs in extent from that which would be produced by an equal quantity of sulphur. We may therefore assume, as in the case of sulphur, that the temperature of the compound formed is always the same, under the same conditions, and is always higher than that of its constituents in a free state.

It will be noticed that the compound formed, phosphorus pentoxide, is a solid at ordinary temperatures, although at higher temperatures it is a gas. A comparison of the temperatures of the two compounds at the time of formation cannot therefore be made from the final change of temperature produced in the water; for we have learnt that the change from a gas to a solid is itself accompanied by a thermal change. The comparison can only be made after determining what is the thermal change equivalent to the solidification of a known quantity of phosphorus pentoxide.

When two solutions act upon another, the thermal change taking place is complex, and its measurement attended with great difficulties. When new substances are formed, a change of temperature is expected from previous observations. We know that the same thermal changes in different kinds of matter are not equivalent; and we may have here several new substances formed at the same time, under such circumstances that thermal equilibrium rapidly takes place before the specific temperature of each at its moment of formation can be measured. In some cases there is the further complication of change of state, for one of the new substances formed may be insoluble, and appear in the solid state as a precipitate. These are some of the difficulties which have to be overcome before correct determinations can be made of the thermal changes which always accompany chemical changes.

95. Dalton's Atomic Hypothesis and its later Development.—The conception of all matter as being constructed of very minute separate particles, atoms, prevailed among Greek philosophers at a very early date. Their opinions, however, have little in common with modern views. In the year 1808 John Dalton published his 'New Principles of Chemistry.' He embodied the older guesses in a systematic hypothesis, which aimed at a complete explanation of the fact then known, that compounds have an invariable composition. According to his views, the formation of a chemical compound is an action taking place between indivisible atoms. Since all the atoms of the same kind of matter are absolutely alike, the relative masses of two substances combining will be the same as the relative masses of the atoms. These relative masses were all expressed in terms of the smallest as unity, which was found to be that of hydrogen. The numerical values thus obtained were called atomic weights.

An example will make Dalton's hypothesis clearer. Water is proved to contain always the same relative quantities of oxygen and hydrogen, viz. 8 to 1. It has an invariable composition. Each particle or atom of water will therefore contain 1 atom of oxygen and 1 atom of hydrogen; and an atom of oxygen is eight times heavier than an atom of hydrogen.

We are now aware that, if the volumes of oxygen and hydrogen combining to form water are observed, the volume of the hydrogen will be found double that of the oxygen. If Avogadro's hypothesis be true, there will be twice as many distinct particles of hydrogen as of oxygen in water. Dalton's hypothesis, therefore, does not agree wholly with all observations.

Dalton had observed that, when two substances form more than one compound, the relative quantities in one compound bear a simple ratio to the relative quantities in another. For example, he found that a certain quantity of carbon united with a certain quantity of oxygen to form one oxide of carbon, while it formed another oxide by uniting with just double that quantity of oxygen. Likewise, a certain quantity of carbon unites with a certain quantity of hydrogen to form

one compound, while it forms another compound by uniting with double the quantity of hydrogen. An atom of one oxide of carbon, he said, contained one atom of carbon united with one atom of oxygen, while an atom of the other oxide contained an atom of carbon united with two atoms of oxygen. He similarly explained the structure of the two compounds of carbon and hydrogen.

The smallest particles of a compound are now called molecules, the word atom being used to denote the ultimate particles of elementary matter. The structure of a molecule of a compound cannot be decided until many more investigations have been made. We may say that it is separable into unlike parts, if the atomic hypothesis have any truth in it; but we cannot yet say how many of these parts there are, although we may assert that there must be at least as many as there are individual constituents.

By observing the relation that exists between the volumes of combining gases and the volumes of the gases resulting from their union, we gather that the molecules of elementary gases must be divisible into at least two parts. It is to these parts that the term atom is now given. For example, equal volumes of the gases, hydrogen and chlorine, unite to form a compound, hydrogen chloride, which is a gas occupying the same volume as its components together occupied before combination. That is, if we accept Avogadro's hypothesis, one molecule of hydrogen and one molecule of chloride form two molecules of hydrogen chloride. But each of these molecules of hydrogen chloride contains some of the substance hydrogen, and some of the substance chlorine. In other words, the molecule of hydrogen is now divided into two portions, and so is the molecule of chlorine. In accordance with the system of symbolic notation used in Chemistry, H_2 is written for the molecule of hydrogen, while H represents an atom of hydrogen. The reaction taking place is represented by the following chemical equation:—

$$H_2 + Cl_2 = 2\ HCl.$$

Or, one molecule of hydrogen unites with one molecule of chlorine, forming two molecules of hydrogen chloride.

We have observed that a given volume of oxygen unites with double its volume of hydrogen. If Avogadro's hypothesis be true, then each molecule of water must contain at least twice as many particles of hydrogen as of oxygen. But this observation alone tells us nothing more. When we come, however, to measure the densities of hydrogen, oxygen, and water, under precisely the same conditions, *i.e.* at a temperature at which water is a gas like its components, we find that water-gas is nine times, and oxygen sixteen times, as heavy as hydrogen. These numbers must, from Avogadro's hypothesis, also stand for the densities of those particles, which are contained in equal number, in equal volumes under the same conditions. That is, these are the relative densities of molecules of water, oxygen, and hydrogen. The molecule of hydrogen being taken, since it is the lightest, as the standard, and, since it is supposed to contain two atoms, being called 2, then the corresponding numbers for water and oxygen will be 18 and 32. These numbers are called molecular masses. The molecule of water must therefore contain one atom of oxygen and two atoms of hydrogen, and is written shortly as H_2O, while the reaction will be expressed by the following equation :—

$$2\,H_2+O_2=2\,H_2O.$$

Or, two molecules of hydrogen uniting with one molecule of oxygen yield two molecules of water.

It must always be remembered that the numerical values called atomic masses require to be very clearly distinguished from those relative quantities of different kinds of matter which have been found by experiment to be chemically equivalent. Chemical equivalents are based upon the results of observation. They cannot be altered, except so far as modes of measurement may become more accurate, for they represent facts of nature. On the other hand, atomic masses are values which are based upon theories, and chiefly on the theory of Avogadro, which may perhaps have to succumb to facts not yet observed. It is true that atomic masses are derived from chemically equivalent quantities, and are always simply

related to them, sometimes coinciding with them; but the theories by means of which they are derived gain no confirmation from the process. The strongest reason which we have come across in our past observations for supposing that atoms have a real existence, and that the atomic masses represent their relative masses, lies in the fact that the supposed relative masses of atoms are those masses which are thermally equivalent. On the other hand, chemical equivalents agree with electric equivalents. The obvious suggestion is that changes of temperature are changes in the atom as a whole—changes, in fact, in the motion of the atom—while chemical and electric changes are disturbances of a state of equilibrium which many considerations urge us to regard as very complicated.

Additional Exercises and Questions.

1. Heat small quantities of iodine, ammonium chloride, and lead nitrate. Plug the vessels with cotton-wool. Compare the changes taking place, and closely investigate the substances when they are cold.

2. Perform an experiment with a view to proving that chemical change causes no alteration in the total amount of matter taking part in the change.

3. Analyse roughly, by using phosphorus, the air which has been held in solution by rain-water, and state whether your results, when compared with the analysis of ordinary air, would lead you to describe air as a chemical compound or a mixture of gases. The air may be expelled from the water and collected by filling a flask, and a tube in connection with it, completely with the water. The tube is bent so as to dip beneath the mouth of an inverted vessel standing over water and containing water. The water may be renewed in the flask until sufficient air is obtained.

4. Place moist iron powder (not filings, which are generally oily) in a confined volume of air over water, and leave for several days. The larger the surface of powder exposed, the quicker will be the change.

5. Substitute oxygen for air in the experiment in Section 89.

6. Observe the action of acids and alkalies on litmus. Observe, by the use of litmus, that definite quantities of acids are required to 'neutralise' definite quantities of alkalies. Use burettes.

7. Prepare some solid sodium chloride from hydrogen chloride and sodium hydrate.

8. Collect, measure, and examine separately the gases which are given off at the points where very dilute hydrogen sulphate makes contact with an electric circuit. Use platinum plates for making contact.

9. Add an acid to calcium carbonate (marble or limestone) and cause some of the gas to pass through a solution made by shaking up with water another portion of the calcium carbonate after it has been strongly heated for some time. Observe that the same result is given, if air from the lungs, or air in which a substance containing carbon has been burnt, be passed through some of the same solution, and also that the calcium carbonate loses the gas under observation, when it is at a high temperature. Prove also that this gas is contained in the atmosphere in small quantities. Show that the white precipitate formed contains the same gas, and is therefore calcium carbonate.

10. Arrange an experiment to show that air will burn in an atmosphere of coal-gas. Force the air slowly through a tube by means of water falling into a vessel with which the tube is connected. Have ready a vessel supplied with coal-gas which is burning at a small opening. Light the jet of air as it enters at this opening and extinguish the gas. Care is needed.

11. Perform experiments illustrating the law that chemical combination takes place between definite quantities of different kinds of matter.

12. What physical changes usually accompany chemical changes?

13. Suggest some hypothesis as to the manner in which chemical change proceeds and the causes by which it is set up.

14. What facts lead us to believe that the molecule of hydrogen contains two atoms?

15. How are the chemical properties of a body distinguished from its physical properties? How can it be proved that diamond and charcoal are the same kind of matter?

16. How would you proceed to find out whether two gases are alike without making use of chemical methods?

17. What are the experimental facts and theoretical considerations from which the numbers called atomic weights or masses are derived

18. What is *a law of nature*?

CHAPTER VIII

OBSERVATIONS WHICH LEAD TO THE THEORY THAT SPACE IS FILLED WITH A MEDIUM, THE ETHER, BY MEANS OF WHICH CERTAIN MODES OF MOTION ARE CONVEYED FROM ONE PORTION OF MATTER TO ANOTHER

96. On Radiation or Rectilinear Propagation of Light and Temperature.—We have already noticed that thermal equilibrium may come about, without material contact, by means of radiation—a process which takes place independently of any material medium, or, at any rate, of matter as we have learnt to observe it. The effects of radiation may be detected in any direction in space, except so far as they are intercepted by material bodies.

Radiating matter may be recognised either by thermal or luminous effects; that is, we may receive from it the sensation of warmth through our skin, or through our eyes the sensation of light. Although these properties may co-exist, a body which causes a change of temperature in neighbouring bodies does not necessarily affect our eyes.

If a body, *e.g.* a piece of iron, be raised to a high temperature, it will be found that the gradual diminution of thermal radiation, as marked by a neighbouring thermometer, corresponds with a change from whiteness to a yellow, and then red, glow; while considerable thermal radiation will go on after the body has ceased to emit any light of its own. The same phenomena occur in reverse order as the temperature of a body rises. It is important to distinguish between the sensation of light and its cause, and the sensation of warmth and its cause, and also to remember that temperature is a condition of matter. We are now primarily concerned in finding out

what is the condition of space through which effects of light and temperature are being propagated.

The interception of light by an opaque body from the portion of space *shadowed* by it is readily explained by the propagation of light being rectilinear. A corresponding space, shadowed from thermal radiations, by a body which is thermally opaque, may be readily shown to exist by means of a sensitive thermometer. Within this space no change of temperature is produced by the radiating body.

Occasionally it may appear that thermal radiation is greater in an upward direction than others; but this may be shown to be clearly due to the ascent of air which has been heated by contact with the hot body, and so made less dense than the surrounding air. Radiation may be shown to proceed in a vacuum just as in the air; while it comes from the sun and stars through vast spaces free of air.

That effect of radiation which we call light is much more readily and discriminatingly observed than the thermal effect; and in the following pages greater attention will be paid to the sensations of light in consequence.

97. Reflexion.—When radiation falls upon the surface of any kind of matter, it is in some degree turned back or reflected. If the surface be irregular, there will be irregular reflexion; but the smoother the surface, the greater the fraction undergoing regular reflexion. It is by the light reflected from bodies that we perceive them, and it is by the manner in which light is reflected from various parts of the same body that we judge of its shape. Without paying attention to the extent of reflexion, we may indirectly verify the following laws, viz. that the angles, which the incident and reflected light make with the normal at the reflecting surface, *i.e.* the angles of incidence and reflexion, are equal, and in the same plane.

A plane mirror, which may be either silvered glass or plate glass, is used, and two cross-wires mounted on a ring serve as an object affording light suitable for the observation of reflexion. If silvered glass be used, a strip in the centre is scraped off so that the cross-wires of a similar ring may be visible at the

back of the mirror together with the image of those in front. Place the two cross-wires so that the image of the one in front appears to coincide with the visible portion of the one behind, and adjust carefully until the coincidence is maintained when the eye is moved from side to side.

Instead of two cross-wires, two pins fixed vertically, one in front and one behind the mirror, may be used. They are placed so that the upper part of the one behind is visible, and may be compared with the image of the lower part of the one in front.

If the distances of the objects from the mirror be now taken, they will be found equal. If the law of reflexion stated above be assumed to be true, then the results here observed would follow, and hence we may consider the law to be indirectly demonstrated by these experiments. Let *a b* be the plane mirror, and *c* and *d* the cross-wires, at an equal distance in the same straight line from the mirror. Then assume a single ray of light, from the point of intersection of the wires in *c*, to be reflected, after meeting the surface at *e*, making the angle *c e g* equal to the angle *f e g*, when *g e* is the normal at *e*. Then it is easy to prove by geometry that the line *f e* continued will meet the cross-wires *d* at their point of intersection, for the angles *c e k* and *d e k* are equal (*d e k* being equal to *a e f*), and *d k e* is equal to *c k e*, each being a right angle, and *k e* common to the two triangles *e k d*, *e k c*.

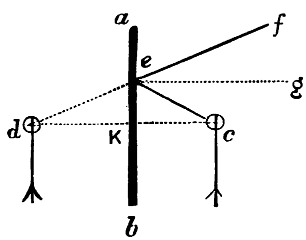


Fig. 50.

Therefore the triangles are equal, and likewise *d k* to *k c*. Hence the eye placed anywhere on the line *e f* will perceive the object *d*, and the image of *c* at the same position, provided only the law be true.

98. To find the Focal Length of a Concave Mirror and of a Convex Lens.—A needle or pin is fixed vertically in front of a concave mirror, and the position, in which the eye will see an inverted image of the needle, is found. It is advisable to

cover the mirror, if large, with dull black paper, leaving a small hole at the centre for observation. The needle is now adjusted until the point of the image just touches the point of the needle, and agrees with it in size. The coincidence must be maintained when the eye is changed in position.

When this adjustment is made, and the distance of the needle-point from the mirror measured, it will be found to be the same as the radius of the spherical surface of which the mirror forms a part—that is, the needle-point and its image are at the geometrical centre of the reflecting surface. This may be proved by using the spherometer to find the curvature of the mirror. Knowing that the three fixed feet of the spherometer are equidistant, and form an equilateral triangle of side l (which may be measured), and the distance, a, through which the centre leg has been moved, we get from Euc. iii. 35, if r stand for the radius of the sphere of which a segment, of thickness a, has been cut off by the plane of the triangle,

$$a\,(2r-a)=\frac{l}{\sqrt{3}}\times\frac{l}{\sqrt{3}}=\frac{l^2}{3},$$

whence $$r=\frac{l^2}{6a}+\frac{a}{2}.$$

$\frac{l}{\sqrt{3}}$ is the radius of the circle circumscribing the triangle formed by the legs, and corresponds with the distance $a\,b$ in fig. 51, $b\,e$ corresponds with a, and $d\,b$ with $2r-a$.

Half the distance thus found is called the focal length, or the focus is a point midway between the mirror and its centre of curvature.

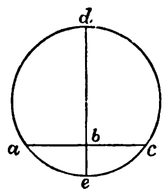


Fig. 51

When light passes through a transparent body, it is changed in direction, except when it is normal to the surfaces of entrance and emergence. When the body is shaped like a lens, certain properties, varying with the shape and material of the lens, are the result of this change in direction of transmitted light.

We may measure the distance from the lens of the image, which is produced by the light from an object passing through the lens, by means of an optical bench (fig. 52). This consists of a long wooden horizontal stand, along which may be moved vertical stands holding the luminous object, the lens, and a screen of white unglazed paper to receive the image. Each of these stands is made so that the uprights may move perpendicularly across the long scale A of the bench, which is shown in section at X. The lateral movement is obtained by a block sliding in a groove, as shown at C, in Y and Z. The longitudinal movements of the stands are measured by a stand carrying a horizontal wire, the length of this wire being known and added to the distance through which its stand is moved in

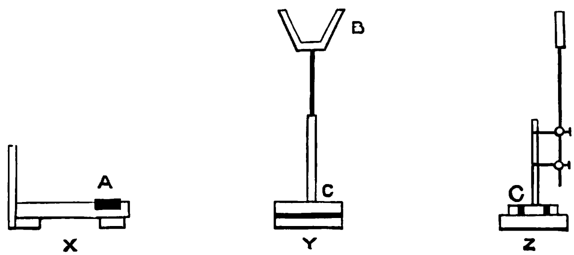


Fig. 52.

taking a measurement. Screws at D and E enable the screens, lenses, or mirrors to be adjusted in height. Good observations with lenses and mirrors can be made on such a bench.

In the stand for the luminous object place a screen with a central aperture and a pin vertically fixed with its point at about the centre of the hole. Close behind this place a strong light. The lens and screen are now adjusted until a clear image of the pin-point is obtained. It will be found that for every change in the distance of the luminous object from the lens there is a change in the distance of the image from the lens. The points thus found are the conjugate foci.

If the light from a distant object be made to pass through the lens, it will be found that the image formed has an invari-

able position with regard to the lens. This distance is called the focal length. In order to succeed with a distant object, such as a vane or flag-staff, diffused light must be shut off as much as possible from the lens and screen.

99. The Formation of a Spectrum.—Place a lamp in front of a vertical and narrow slit, and allow the thin ray of light which passes through the slit to fall upon the face of a glass prism at a suitable angle which is ascertained by trial. The ray is found not only to be turned aside but to yield a horizontal ribbon of many colours, called a spectrum, which may be shown upon a screen.

By interposing a convex lens between the prism and the slit, the spectrum becomes more distinct and definite; and, by viewing the spectrum through a telescope, it is enlarged. The amount of refraction suffered by the ray, as well as the extent to which it is dispersed or spread out into these colours, is determined by the angle and material of the prism.

The spectroscope is an instrument in which these operations are carried out effectively and simultaneously. The tube containing an adjustable slit, and the lenses, by which the ray is prevented from diffusing, is called the collimator. The other tube is the telescope through which the spectrum is enlarged without being otherwise altered. The telescope is first removed, and the eye-piece adjusted so as to present a clear image of the cross-wires, which are inserted for exactness in comparing distances. The eye-piece and cross-wires are then focussed together, so that a distant object yields a clearly defined image, which should not vary its position with regard to the cross-wires when the eye is moved from side to side. Remove the prism and replace the telescope, turning it and levelling if necessary, so as to view the slit directly and in the middle of the field. If necessary, focus the collimator, so that the image of the slit is well defined. Replace the prism in such a position that a good horizontal spectrum is obtained, levelling if necessary. The axes of the telescope and collimator, together with the graduated circle to which they are attached, should now be in the same plane, if the adjustments have been carefully made.

Instead of an ordinary white flame for illuminating the

slit, we may now use the incandescent vapour of various substances by placing them on platinum foil in the Bunsen flame. Instead of the continuous spectrum we shall observe bright lines varying in colour, number, and relative position with the substances used. By throwing the rays of the sun upon the slit by a reflector we obtain a continuous spectrum containing certain dark lines to be afterwards explained.

We may reasonably assume from this experiment that variety of colour is caused by the varied action of bodies upon white light. A red object absorbs that portion of white light which is not red, and reflects the red light alone.

It is important to note that thermal dispersion is observable, and also thermal reflexion and refraction; but the thermal effects of radiation are more troublesome to deal with than light.

100. The Interference of Light.—It was first noticed by Young that two rays of light, converging in a dark room from two small holes close together, yield certain alternate light and dark bands, when a screen is placed where they overlap. The dark bands disappear when one ray is cut off. In other words, the addition of light may, under certain circumstances, produce darkness. We have already learnt from the use of a prism that white light is the joint effect of light of various kinds or colours, and this is again shown by the observation that with white light the dark bands are alternated with coloured ones in this experiment, while with light of one colour, such as the yellow light given by sodium compounds, alternate bands of black and yellow alone are given.

Fresnel obtained a similar result more conveniently in two ways: one by the aid of reflexion, the other by means of refraction. In the first method two metallic mirrors, *a b* and *b c*, are placed side by side, so as to be nearly in the same plane, but not quite. A ray of light from *d* is caused to fall upon both mirrors. The reflected rays converge to a point *f*, and apparently come from two vertical images, *g* and *h*, close together at the back of the mirrors. On placing a screen at *f*, alternate dark and light bands should be obtained.

In Fresnel's second experiment a prism *a b c* of very large

angle, nearly 180°, called a bi-prism, is placed so that light diverging from the point *d* falls on the face *a c*. Part of the light is refracted by the portion *a b* and part by the portion *c b* of the bi-prism. A given ray *d e* is refracted and reaches a point *p*, as if it had come from *g*, while another ray *d f* is

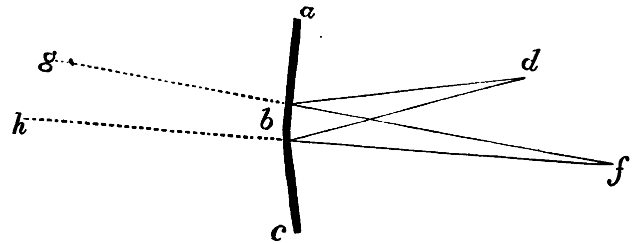


Fig. 53.

refracted by the other portion of the bi-prism and reaches the point *p* as if it had come from a point *h*. Hence the effect of these two rays at the point *p* is the same as if they had come respectively from the two points, *g* and *h*, which are close

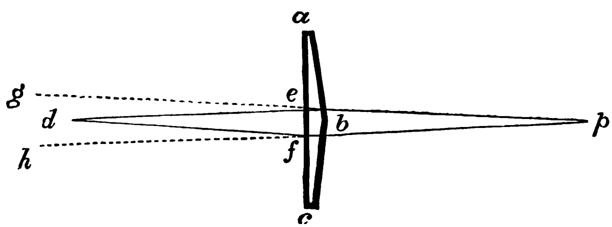


Fig. 54.

together, and hence a screen placed at *p* will exhibit interference effects.

A carefully constructed optical bench allows this effect to be observed, and the distance apart of the lines to be accurately measured. It consists of a heavy iron bar, planed, grooved, and graduated so that three upright stands may be

moved along it to distances measurable by the verniers they carry. The first stand carries the eye-piece with a vertical cross-wire. This may be moved horizontally by a micrometer screw. A scale and vernier shows the displacement. The middle upright holds the bi-prism and the further one carries the slit. These two are capable of horizontal and vertical movements. The centres of the slit, bi-prism, and eye-piece should be in a straight line parallel to the bench-scale. The edge of the bi-prism should be vertical and pass through this straight line. The cross-wire and slit should coincide with the edge of the bi-prism, and the cross-wire must move accurately at right angles to this line, in order to measure the distance apart of the interference lines.

101. Explanation of Interference.— The most complete explanation of the previously observed properties of light is given by the wave theory, according to which light consists of a vibratory motion of a universal medium, called the ether. The ether allows this vibratory motion, when once it is set up, to be propagated with very great rapidity and with undiminished intensity in all directions. Ether is present in matter as well as in space, occupying the spaces between the particles. Light may therefore pass through some kinds of matter; others are only slightly penetrated, the motion of the ether being probably obstructed or changed by the particles of matter. We are unable to observe ether directly; we are not conscious of its existence as we are of matter; yet, by assuming the existence of such a medium, we are able to put forward a simple explanation of the most varied optical phenomena.

We are not concerned, at this stage, with the exact nature of the vibratory movement constituting light. We have simply to consider that this vibratory movement is rapidly propagated without any portion of the ether undergoing more than a small excursion from its position of rest, just as a wave of water travels far and wide, while a body floating on the surface of the water shows by its motion up and down that the wave travels, but not the water. The movement travels on, leaving the ether behind it unchanged. If it reaches our eyes with sufficient intensity, we are conscious of light. If it

reaches the skin with any intensity, we have the sensation of warmth. When it falls upon a body, it may make it luminous or raise its temperature.

Whatever may be the state of the ether which is conveying radiation, we may be quite certain of one thing—that there are two phases of that state. At one time the movement is positive, at another negative. At one instant the displacement is in one direction, at the next it is equal in amount but opposite in direction. The distance between two points which are successively moving in the same manner is called the length of a wave or undulation. In other words, the length of a wave is the space through which the vibratory movement passes during the time occupied in the complete vibration of any single portion of the ether through which the wave is transmitted. The total displacement of each portion of the ether from its original position is called the amplitude of the wave. Upon this depends the intensity of the light (and likewise of the thermal effects produced).

When a given point is in the paths of two ether waves, their joint effect may be either an increased or diminished displacement—that is, the amplitude of the joint wave at the point of coincidence may be larger or smaller than that of either of its constituent waves. The movement communicated by one travelling wave may be, at that given point, in the same direction as that communicated by the other wave. In this case the total displacement is equal to the sum of the separate displacements, and the intensity of light is greater than that from either source alone. If the displacements happen to be, however, in opposite directions, on account of the position of the point with regard to the concurring waves, then the resultant displacement will be the sum of a positive and a negative quantity, *i.e.* the difference between these quantities, and the direction will be that of the larger quantity. Hence there will be a diminution of light. If the two displacements are exactly equal and in opposite directions at the given point, then there is evidently no resultant motion at this point, and hence no light. It is obvious that displacements which neutralise one another must be in the same plane, and in the case of

light this plane must, from our observations, be perpendicular to the direction of propagation. Confirmation of this may be obtained from the polarisation of light.

In order to measure the wave-length λ of a given kind of light it is necessary to know the distance x between two consecutive bright bands, the distance a between the slit and the eye-piece, and the distance C between the two virtual images formed by the two halves of the prism. Then,

$$\lambda = \frac{Cx}{a}.$$

By varying the light, or interposing coloured glasses between the slit and the bi-prism, the variation in wave-length may be measured by the same formula, the quantity x being the only variable. We shall find that the colours in the order in which they are presented in the spectrum vary in wave-length, the smallest wave-lengths being at the violet end, and the longest at the red end, the intermediate colours having intermediate wave-lengths.

102. Explanation of Rectilinear Propagation.—Although the wave theory of light has simply and reasonably explained several phenomena, we have got to find some explanation for the observed rectilinear propagation of light, and for the observed laws of reflexion and refraction. It is contrary to observation that a source of light should travel in one direction only. It is visible in all directions except so far as opaque matter prevents its passage. It would also be inconsistent with our assumption of the existence of a homogeneous ether to suppose that a disturbance, set up by a radiating body, does not travel in the same manner, and with the same speed, in all directions in the same isotropic medium. We have, in fact, since the sphere is the only body which is symmetrical in all directions with regard to space, a series of spherical waves extending further and further until obstructed or modified. When the surface of another medium is reached, we have in general two new waves set up, each different in direction from the original. One is the reflected wave, the other the refracted wave. The relation in the amplitude of the vibrations, by

which the intensity of the two waves of light is determined, will vary for different media. In the same medium the speed is unchanged. In the new medium the speed may naturally alter. It has been clearly proved by direct observations that the speed of propagation does vary in different media; but, whatever the speed, light always travels rectilinearly. We may, however, first of all apply the principle of interference to reconcile the wave theory with the observed fact that an opaque body effectively shields a portion of the ether from disturbance which must be occurring in its neighbourhood.

Let W V represent a section of portion of a wave, starting

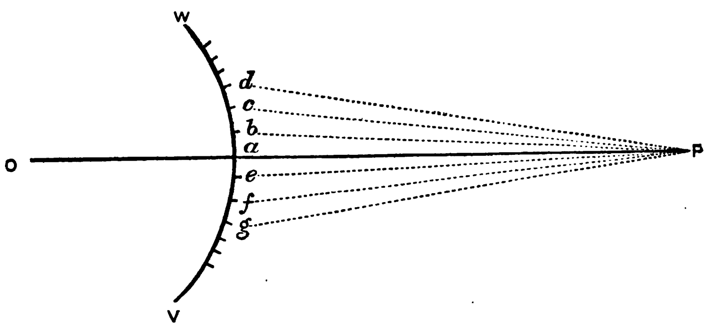


Fig. 55.

from the luminous point O, and let P be the point at which the effect of this wave is considered. Join O P cutting W V in *a*, then let *b*, *c*, *d*, *e*, *f*, &c., represent points such that the linear distances *b* P, *c* P, *d* P, &c., on one side the line *a* P, and likewise those, *e* P, *f* P, *g* P, &c., on the other side, each differ from one another by the distance of half a wave-length. Then, if we consider each of these points as the centre of a new disturbance, it is obvious that each consecutive pair of the secondary waves produced will arrive at P in opposite phases, and, if equal, would neutralise each other. That is, the general result of the portion *a b* will be opposite to that of the portion *b c*, and *c d* opposite in its effect to *d e*, and so on for the other

portions of the wave. But now, as the distance from a increases, the consecutive portions of the wave become more nearly equal in area, and at a distance which is very small, on account of the minuteness of the dimensions of light-waves, the areas become practically equal, and joint disturbances from consecutive areas become equal and opposite in their effects. Hence the effective portion of the wave is a small area around the point a in the straight line joining the luminous point with the point of investigation P. Hence an obstacle placed at this point a shuts off the light from P.

One important result of this explanation is that, if alternate portions, $b\,c$, $d\,e$, &c., be stopped by opaque bodies, the total quantity of light reaching P will be increased. This will now be demonstrated by means of an interference grating.

103. The Interference Grating.—In observations with this grating we shall deal with light-waves of one kind—that is, of the same length—for the sake of simplicity. The grating now used consists of a number of very fine and very close parallel lines, which have been accurately ruled at equal distances by means of a machine on a piece of glass. A photographic reproduction of such a grating answers every purpose. This is now placed in a vertical position on the small central table of the spectroscope, so that the yellow sodium light from the slit of the collimator falls upon it normally. On looking through the grating towards the slit, the direct image of the slit will be seen, and, in addition, several images on each side of the direct image growing fainter and fainter as they increase in distance. On bringing the cross-wires of the telescope to bear upon these images, and carefully adjusting, if needful, the level of any portion of the instrument, their angular distance from the central image, and from each other, may be very accurately read.

Let $a\,b$, $a_1\,b_1$, $a_2\,b_2$ represent in section the opaque portions of the grating, P the position of the eye, and O the slit; then we may consider the grating to coincide with a very large light-wave, alternate portions of which are cut off by the opacity of the lines, while alternate portions are transmitted—a condition described in the last section Without

the grating we should see the slit directly ; by means of the grating the interfering portions are intercepted, and so more than a direct view of the slit is obtained, and we see, in a fashion, around a corner.

Suppose that the distances of P from a_2 and from a_3 differ by a whole wave-length, then the light which would come from the portion $a_2\,a_3$ of the large wave may be considered to

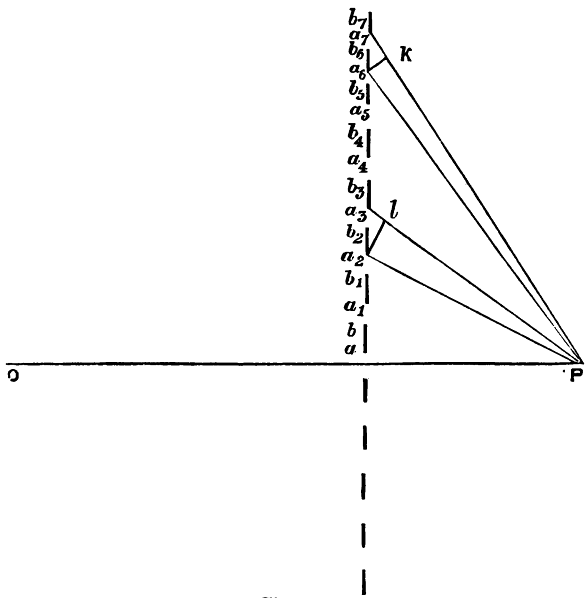


Fig. 56.

consist of two portions, which are nearly equal but in opposite phases; the line $a_2\,b_2$, however, intercepts one portion completely, or incompletely, according to the relative size of the opaque and transparent portions. A bright band will consequently be seen at P a_3, and this will be the first band. At another position $a_6\,a_7$ on the grating, the line P a_6 will differ from P a_7 by two whole wave-lengths ; then the light which

would come from the portion a_6 a_7 may be considered to consist of two portions which will be in opposite phases. One of these being intercepted, a band is visible in the direction P a_7, and so on, for all portions of the grating, where the corresponding distances differ by any whole number of wave-lengths. The position of these images will be determined solely by the length of the light-waves, and will vary for different colours.

If d denote the distance a_2 a_3, &c., that is, the interval composed of an opaque and a transparent portion of the grating (a distance which is usually known for each grating), and λ denote the wave-length of the light used, then, by construction, for the position of the first image,

$$\frac{\lambda}{d}=\sin\theta. \quad \text{Or } \lambda=d\sin\theta$$

when θ is the angle a_3 a_2 l or, which is the same, the angle O P a_3; for the second image and the second angle θ_2,

$$\lambda=\frac{d}{2}\sin\theta_2, \text{ and so on.}$$

It is advisable in this observation to take the mean angle, obtained by measuring the corresponding images on each side of the main image. Precisely the same results, explicable in the same manner, may be obtained by reflexion from lines ruled upon polished metal. When white light is used a series of pure spectra may be obtained with either reflexion or refraction gratings, since we shall have each monochromatic image of the slit replaced now by a band, representing the superposition of successive images, caused by the radiations of successive wave-lengths. By constructing a diagram which shall include radiations of different wave-lengths, the difference in position of the images will be made clear.

104. Explanation of Reflexion and Refraction.—The same principle of interference of light may now be applied to explain the observed laws of reflexion and refraction in isotropic media—that is, media which do not interfere by their structure with the spherical propagation of ether-waves.

Each portion of the bounding surface of two such media upon which light is incident becomes a centre of disturbance, from which minor waves are rectilinearly propagated in each medium. The effect at a given point P in the one medium is the resultant of all the disturbances which reach it; and the effect at a given point p is the resultant of all the disturbances which reach that point through the other medium. Suppose the incident wave-front be considered, for simplicity, as a straight line $a\,b$ cutting the surface in a. Draw $b\,c$ perpendicular to $a\,b$. [For the clear understanding of the following, it is of the greatest importance that the whole diagram should be accurately copied step by step on a larger scale by the aid of compasses and rulers.] Then from a as centre, and with $b\,c$ as radius, describe the partial circle $d\,q$. By the time the portion of the wave-front at b has reached the surface at C the disturbance originated at a will have spread to all parts of the curve $d\,x$. Take intermediate points e and f on the wave-front $a\,b$, and draw perpendiculars to the surface, and from the points g and h describe partial circles with radii equal to the distance which the portion of the wave-front at b has yet to travel to the surface after these intermediate points have reached it. These distances will be $j\,c$ and $k\,c$, obtained by drawing parallels to the wave-front from the points g and h. A tangent drawn to these curves will now represent the reflected wave-front.

Let us now take several points in the surface $a\,c$, such that the displacements caused at the point m by the waves from consecutive portions x, y, z are in opposite directions—*i.e.* the distance of these points from m must vary by half wave-lengths. Then, as before demonstrated, the only effective portion of the surface in illuminating the point m is the small area at g, the displacement at which has been caused by the portion of the wave-front at e, the areas further away more and more completely destroying one another. The same reasoning applies to every other portion of the reflected wave-front, and hence the light must be reflected in the direction $d\,c$, all the other ether disturbances being neutralised.

It is obvious from the construction that the reflected wave-front is inclined at the same angle to the reflecting surface as

the incident wave-front, and that they are both in the same plane.

To the refracted portion of the wave the same arguments and the same construction may be applied, with the exception of the modification required by the difference in the speed of light waves in the two media. The partial circle, which is drawn from the point *a* in the new medium, must have a radius *a n* which shall bear to the distance *b c* the same ratio as the speed of light in the new medium bears to the speed in the old medium. The same ratio must be observed in the other cases, and a tangent drawn to the several partial circles in the new medium is seen to be deflected on account of the

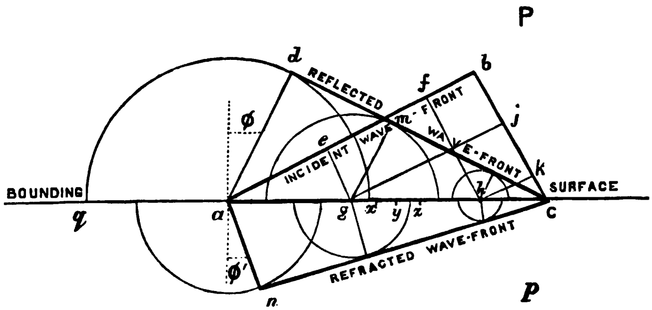


Fig. 57.

change of speed, and may be proved, as before, by applying the principle of interference, to represent the refracted wave-front. The incident and refracted waves are in the same plane, and if ϕ and ϕ' stand for the angles each makes respectively with the normal to the surface, then, by geometry,

$$\frac{\sin \phi}{\sin \phi'} = \frac{bc}{an} \text{ or } \frac{v}{v'}.$$

Or, the sines of these angles are in the same ratio as the speeds of light in the two media, a ratio which is constant for the same media. Hence we may ascertain relative speeds by measuring refractive indices.

A table of refractive indices—that is, of the ratio $\frac{\sin\phi}{\sin\phi'}$,—for yellow sodium light from air is given below.

The most convenient method of measuring the refractive index of a body, if a solid, is to grind it to the form of a prism, measure the angle of the prism by reflection of light with the spectroscope, then measure the angle of minimum deviation when light passes through the substance. If a liquid, it is enclosed in a hollow prism, of which the sides are perfectly plane parallel-sided pieces of glass, which will not themselves cause any total deviation, and measure as with a solid.

Table of Refractive Indices for the mean D line of Sodium.

Diamond	2·42	Crown glass	1·5
Phosphorus	2·22	Magnesium sulphate	1·49
Ruby	1·71	Fluor spar	1·43
Iceland spar (ord.)	1·658	Ice	1·31
„ „ (ext.)	1·486	Carbon disulphide	1·63
Topaz	1·61	Oil of bitter almonds	1·6
Flint glass	1·6	Aniline	1·57
Emerald	1·58	Phenol	1·55
Quartz (ord.)	1·544	Benzene	1·49
„ (ext.)	1·553	Glycerin	1·47
Rock salt	1·54	Turpentine	1·46
Citric acid	1·53	Sulphuric acid	1·42
Canada balsam	1·53	Alcohol (amyl)	1·4
Felspar	1·52	„ (ethyl)	1·36
Potassium nitrate	1·52	Ether (ethyl)	1·35
Potassium sulphate	1·51	Water	1·33
Ferrous sulphate	1·5	Alcohol (methyl)	1·33

105. Explanation of Spectra, with Observations.—In all the previous observations we have paid more attention to the luminous effects of radiation than to the thermal effects, but generally simple experiments suffice to show that the observed changes possess their thermal aspect. For example, the focus of light is the focus of temperature; the direction in which light is reflected or refracted is the direction in which the maximum heating effects are produced by the radiating centre

At the same time we must remember that ether-waves are likely to be checked or absorbed in their passage through various kinds of matter in varying degrees, and that, relatively to the size and condition of the material particles which meet them, there will be some waves more completely absorbed than others. The mutual action of ether-waves and matter forms a wide field of investigation, which our past work should enable us to approach.

White light transmitted through blue glass appears blue because the particles of the glass have absorbed the rest of the white light and let through the blue. So it is for other colours. A coloured flower absorbs a portion of the sunlight incident upon it, reflecting only those waves which confer its particular colour. That a difference of wave-length constitutes variety of colour has been readily demonstrated by interposing coloured transparent bodies, or changing the colour of the light, in interference experiments. The distance apart of the interference bands varies with various colours, and gives an opportunity of comparing the wave-lengths corresponding with the different colours. The dispersion of white light in passing through a prism is brought about by the fact that the speed of the small waves is more checked than that of the larger waves in passing through the denser medium, and small waves are consequently the more refracted. A reference to the diagram explaining refraction will make this clear.

The dimensions of the wave-lengths, found by experiments, are of the same magnitude as we should expect to find for waves originated and influenced by particles of a size consistent with the molecular theory. Ether-waves, molecules, and atoms are physical phenomena of the same order, incapable of being directly observed, but apparent to reason. The nature of the movements, among particles of matter, which give rise to these ether-waves remains a matter for future investigation. So far, we can only say that it is a kind of vibration. When the temperature of a body rises, the vibration increases in amplitude and may change in character. A solid or liquid at a very high temperature emits white light, the constant

collision of particles probably brings about all kinds of vibrations, and hence all kinds of ether-waves, of which many are no doubt invisible. The particles of a gas, unless at a high pressure, suffer fewer collisions, and hence give out a few characteristic vibrations, forming distinct line spectra. Our main source of light, the sun, emits waves of all lengths, not only white light and heat, but waves which do not affect our senses, some of them having been made apparent by special means. This is what we should expect from such a body as the sun. The special line spectra from which so much may be learnt as to the composition of bodies must be studied cautiously. We shall find that the spectrum characteristic of a given body at a given temperature is not necessarily the same as its spectrum at another temperature, or as the one yielded by an electric discharge passing through it. Also, a change of pressure may bring about modifications. Although conclusions must not be drawn too freely from spectroscopic observations, since a given vibration may be due to several others combining, or may be modified by neighbouring particles, yet they have become a most important means of analysis, far exceeding in delicacy any other method. New conceptions also as to what is truly elementary matter have been gained from spectroscopic investigations.

Another important branch of spectroscopic work is the investigation of the results of transmitting ordinary light through incandescent vapours. We find under certain conditions that the usual characteristic bright lines are replaced by dark spaces. In other words, the characteristic vibrations previously emitted are now absorbed. The particles of the vapour select and check those vibrations which are, as it were, attuned to their own periods. It is obvious if this result is to be obtained that the vapour must not be at a temperature high enough to yield of itself a bright spectrum. The absorption lines are conveniently seen in the spectrum of the sun, which shows numerous dark spaces corresponding with the bright lines emitted by known terrestrial vapours. A colder envelope of vapours of very complex composition sifts various portions of the otherwise continuous spectrum of the sun. A

good reflexion grating with a heliostat exhibits these lines very satisfactorily.

The main result of our observations of the movements of ether should be to impress upon us the need of considering it as a possible agent in all our experiments. We have seen that it is capable of handing on the state of one portion of matter in one place to another portion in another place; we have seen that this is performed in a peculiarly subtle manner, and we can never consider that any of our knowledge of natural changes approaches completeness until we understand, not only the changes of matter so called, but the changes of the ether in its neighbourhood. In the future, the probable ether movements corresponding with magnetic and electric disturbance will have to be investigated, as well as further details about the theory of light which may be gathered from what is called the polarisation of light. We have to remember that accuracy depends upon completeness of observation; a minute change, if unobserved, may overthrow an elaborate structure of theory. At the same time we have to remember that, the deeper observation goes, the more there is to observe.

Additional Exercises and Questions.

1. Find the angle of a prism by reflexion, from each of its faces, of light from a small body. The angle made by the two reflected rays will be double the angle of the prism. Also find it by ascertaining the angle through which the prism needs to be moved in order that a ray from a small body may fall upon the two faces in succession and be reflected in the same direction. The angle through which the prism has been moved, together with the angle of the prism, should be equal to 180°. Draw diagrams in explanation of each process, and then use a spectroscope. Preliminary observations may be made with a prism placed upon a piece of paper, upon which lines may be ruled to coincide with the directions of the rays and with the angle and movement of the prism.

2. Produce a spectrum on a screen by use of a slit, lens, and prism, and show that the colour of a body is not an inherent property by placing it in different parts of the spectrum.

3. Find out whether a reflecting surface be plane or curved by ascertaining if it reflects regularly. Focus a telescope upon a small body, then incline the surface so that a reflexion of the body may be seen

from its surface. If it be plane, the image remains clear and well defined.

4. Observe by sounding a tuning-fork, and slowly turning it when held near the ear, that an interference of sound-waves, comparable with the interference of ether-waves, may take place.

5. Draw a diagram which will explain the formation of a spectrum from a ray of white light on the hypothesis that waves of different lengths are differently retarded in passing through a prism of dense material.

6. Explain why a parallel-sided transparent body merely changes the path of a ray of light without decomposing it.

7. What information as to the size of the ultimate particles of matter can be gained from the undulatory theory of light?

8. Draw diagrams, and construct models with wires or suspended bodies, to illustrate wave propagation and the interference of waves.

9. The thermal focus coincides with the optical focus in the case of a mirror but not in the case of a lens. Why is this? Is the focal length of a lens the same for all kinds of light?

10. Draw a diagram showing the course of light and the images formed when a candle is placed between two plane mirrors inclined at an angle.

11. Why is the foam of clear water white?

12. Draw a diagram showing the method of obtaining an absorption spectrum.

13. Explain how a spectrum can be formed by an interference grating.

14. How can the colours visible upon a very thin soap-bubble be explained?

15. What is known as to the rate at which light travels? Distinguish between 'wave-length' and 'period' as applied to light.

16. Suggest an explanation of the various line spectra exhibited by glowing vapours.

17. What are the supposed properties of the ether?

18. It is said that all exact scientific knowledge is based upon the measurement of matter and motion. Discuss this statement.

APPENDIX

1. Observations of Quantity of Matter. Balances.—The delicate structure of balances makes it necessary that they should be used with great care. They should be periodically inspected, and all dirt removed. The knife-edges and planes, when made of steel, must be kept free from rust. When balances are fitted with a case, they may be kept free from oxidation by drying the air in the case with strong hydrogen sulphate or calcium chloride. These substances must be periodically renewed. It is obvious that freedom from chemical fumes is essential to their preservation, hence they should be placed in a room cut off from the working chemical laboratory. In addition, a balance should always be placed in a good light, and on a steady table or bracket. For physical observations the large open balances illustrated are very suitable, and are readily adapted for weighing bodies in liquids. It must be remembered that large masses tend to strain the beam, and sudden or uneven movements may diminish the accuracy of the suspension. For this reason the beam should be placed in suspension with a steady movement, and stopped from swinging when the pointer is in the centre of the scale. Of course, alteration of the masses in the pans must only take place when the balance is at rest and supported. Before using a balance it should be dusted, if necessary, and made to swing, in order to test its accuracy of adjustment. If it swings equally on each side of the scale, or if it swings nearly equally, it is ready for use. It is better to allow for a little inequality of swing than to constantly alter the adjustment. Sometimes it is difficult to get the balance to swing. In that case, blow one of the pans very gently. Do not weigh bodies when hot, as the surrounding air becomes heated and ascends, thus making an upward current from the pan used. Most substances should not be allowed to touch the pans, for fear of injury to them.

A filter paper on each pan is advisable for direct weighing. It must be remembered that some substances vary in mass during the operation of weighing—for example, hot water rapidly loses matter by evaporation, while calcium chloride would gain by absorbing moisture.

Finally, great care is needed in supervising the manipulation of weights, and in exacting that they are properly used, and properly returned to their right position in the box after every operation. No excuse should ever be admitted for neglect of this important rule. The weights should be counted when in the pan, and also when they are returned to their places. Before using the weights it is advisable for each student to add together all the weights in the set, giving to the smaller weights their correct decimal values.

2. Observation of Dimensions and Densities.—Besides ordinary steel or box-wood scales, it is advisable to have brass pieces let into benches where convenient, to denote distances of a metre and a decimetre. Also longer distances, marked along walls, are often convenient for measuring wires. Standard measures should be always at hand, and as conspicuous as possible, in order that students may become familiarised with them. By encouraging guessing before actual comparison, great help is given in training the eyes to measure distance. This should also be carried on in comparing the capacities of vessels, or the volumes of solids. This is a most valuable kind of training, which should always be carried on in a laboratory, side by side with the more systematic work. The exact form of such indirect training will vary with circumstances and with teachers, but the opportunity of making it very powerful and suggestive will always be present.

Burettes are very convenient for delivering known quantities of liquids; they should be supported by clamps before windows or white walls if possible. The form with caoutchouc tube and clip for delivery is better for beginners than the one with a tap. The use of a float, for more exact reading, may be encouraged. Besides burettes, a small number of graduated cylinders will be required for measuring the volumes of liquids poured into them. A variety of graduated flasks, including some small enough to be weighed on the balances, will also be wanted.

3. Observations of Temperature-changes. Thermometers. —The most serviceable thermometers are the narrow chemical thermometers reading from 20° below zero to 200° Centigrade. Occasionally a wider range is required. The absolute value of the readings may be found to be somewhat inaccurate when tested by the standard

temperatures, 0° and 100° C.; but this does not diminish their value for general use. The exact reading of a thermometer may easily be obtained by sending it for correction to Kew. In using a thermometer it is of great importance to read accurately. To do this practice is necessary. This caution is especially needful in comparing temperature-changes in different kinds of matter, where a large quantity of matter, say fifty grams, may be changed in temperature. A mistake of half a degree is frequent in a beginner. This would mean a mistake of twenty-five times the unit temperature-change (or, as it is called, twenty-five units of heat). At the same time it must be remembered that the temperature of the hand may easily give rise to an incorrect reading. Errors of this kind must be corrected by taking as many observations as possible in as varied a manner as possible. Mistakes in the numerical results of temperature-changes are much more likely to be due to incorrect reading of the thermometers than to inaccuracy of weighing. Accurate results must not be expected, however, unless special precautions are taken, either to allow for the temperature-changes which simultaneously take place in surrounding bodies, the vessels, air, &c., or else to reduce these to a minimum by non-conducting material. Change of temperature taking place more rapidly the greater the difference of temperature in the bodies undergoing it, it is of course advisable to adjust the quantities of matter under observation in a given experiment, so that mutual changes may produce no very great difference of temperature between them and external bodies, such as the air. This is not always possible.

In order to measure the expansion of solids, paper scales pasted to wooden rods or wooden scales to which sliding verniers are attached, will be found sufficiently accurate. Inaccuracy of result is more likely to lie in incorrectness of reading than in incorrectness of graduation, and for this reason the vernier should carry an eyepiece fitted with cross-wires. These may be obtained from a wholesale maker very cheaply.

4. Observations of Fall of Bodies to the Earth.—It is convenient, in observing the fall of bodies to the earth, to have a pulley fixed as high as possible in a room, and, passing over it, a cord, by means of which the electro-magnet, together with the wires needed, may be hauled up to a considerable height with the bodies for experiment adhering. A key for breaking contact will be required. Direct contact of the body with the magnet may be prevented by means of a brass guard more neatly than by a piece of paper.

Results with 'Atwood's' machine are not likely to be more than

approximate, unless comparative methods are used. The construction of the frictionless wheels, however good, cannot eliminate friction. Hence the rate of fall is diminished, while an equivalent rise in the temperature of the apparatus takes place. A good machine, however, affords a very valuable amount of training, and fair results are obtained with a sufficiently long fall. The machine should be placed on a very firm and horizontal bracket, fixed at as great a height as the room will allow. It is essential that pulleys should be well made and set, if anything like theoretical values are to be obtained from the experiments in which they are used. The cost of such pulleys is considerable.

5. Observations of Electrification.—In all observations of mutual action between bodies, due to electrification, it is important that they should be as completely insulated as possible. This is difficult in a moist atmosphere, since the condensation of water on the surface of insulating matter may convert it into a conductor. It is advisable, therefore, to thoroughly clean and dry insulating stands and handles. Careful washing with soda, and then with distilled water, allowing the water to evaporate from the surface instead of using a cloth, is generally a sufficient cleansing; while a large copper tray containing sand and heated by gas is needed for completely drying all objects before use. This should be placed in a convenient position for the experiment table. With electroscopes and electrometers great care and patience is needed, if correct observations are to be made; and with some forms of instruments even these qualities will not lead to success. Every instrument must be investigated to see that its construction is suited in every detail to its object; in other words, to see that it really carries out what it pretends to do. The dissection of instruments in this manner is an important part of scientific training.

6. Cells.—The use of cells for obtaining an electric circuit entails much trouble and work, unless a careful system of cleaning and storing away after work is introduced. The consumable portions and porous vessels should always be removed from the cells, thoroughly washed, and kept always in the same place. The binding screws must be kept bright, and any tendency to corrosion checked. Without rules of this kind the expenses of the laboratory will increase, and, what is more important, untidy and careless work will become common. A small separate room with a large shallow sink is very useful for washing and storing cells, and it enables the working laboratory to keep a more orderly appearance. The Leclanché cell is very generally serviceable, and has the great advantages of being

clean in use and requiring little attention. Some of the dry cells are much to be recommended on the score of cleanliness. The bichromate cell is useful, but the cover containing the zinc and carbons is not generally made solidly enough. The Daniell cell is a most useful form for constant circuits. If Grove cells are used, they should be placed outside the room, as the fumes are noxious. A flat window-sill serves very well for the purpose. Great saving of expense in cells may be effected by buying sheet zinc and copper from wholesale houses, and cutting into required shapes. Porous and glazed pots may also be bought directly from the makers.

7. **Observations of Solution, &c.**—For dissolving solids, beakers or boiling-tubes may be used. These should be made of evenly thin glass. Glass vessels which vary in thickness are very liable to crack. For evaporation, a large free surface of liquid is most suitable; thin porcelain evaporating basins should therefore be used. The larger the diameter the more regular is the evaporation. A copper water-bath is most suitable for slow evaporation, but when the amount of evaporation required is large, it should be commenced more rapidly by more direct heating, as with a sand-bath, and completed on the water-bath. A large water-bath, with openings for a dozen basins, is most economical and least troublesome for class-work. There is however, always a disadvantage in an operation not being carried on, as completely as possible, under the direct control of the small group of boys engaged in it. An operation which is going on in the same manner for all is apt to lose its individuality, and the interest in it is likely to suffer as soon as the feeling of proprietorship relaxes. Competition for accuracy is sure to result from several groups working out, quite independently, the same experiment.

8. **Purity of Substances.**—An important part of the training of a beginner in chemistry is to learn when a substance may be described as pure—when it really contains what its name denotes. Several tests have been described in the previous pages. It must always be remembered that absolute purity is only attained occasionally and with great difficulty, and it is much better that the final stages of purification should be carried on in the laboratory, with the special object of purification in view. It is not reasonable to expect manufacturers to provide pure materials except at very high prices, and it is unwise to lose the opportunities of observation which such operations afford. Nothing can be more misleading than those descriptions of chemical changes which omit to state that the reacting substances are not pure, and which convey the impression that chemical changes are simple enough to be amply described by an equation. They are

often seriously inaccurate in themselves, and conduce to a feeling of certainty when the training of observation has barely commenced. Keenness and faculty of research is thus suppressed, when the aim of even the most elementary work should be to encourage it.

9. Observations of Radiation.—It is essential for many experiments with light, that a portion of the laboratory should be capable of being darkened at will. A room with dark-blinds to the windows is valuable for advanced work, but for beginners and large classes this is evidently not desirable. It is more consistent with good order to have certain portions of benches fitted with supports carrying velvet curtains, which give access to the instruments. The light may be prevented from entering above by placing dusters or cloths at the top as required. Such shielded enclosures serve also for working with mirror galvanometers and electrometers.

It is of great importance that prisms, lenses, gratings, &c., should be handled with care, lest scratches should injure their surface.

In working with the spectroscope, the necessary exclusion from the prism or grating of rays which do not come from the slit is readily obtained by throwing over the instrument a piece of velvet. All spectroscopes should be capable of being used as spectrometers. Hence the central table should be moveable, independently of the larger table. The latter table should be as large as possible, otherwise the movements are cramped, and readings become troublesome. A valuable exercise is contained in the complete adjustment and levelling of this instrument. It should be occasionally put out of adjustment with this in view.

In order to obtain light of a particular wave-length, a Bunsen flame should be used, and the requisite material, placed upon a piece of clean platinum foil, should be supported in the lower part of the flame towards the edge. The most convenient light is the yellow light obtained in this way from sodium chloride or carbonate.

Most of the formulæ connected with reflexion and refraction of light have been omitted as beyond the scope of this book, and properly belonging to a more advanced stage of inquiry. The merely qualitative study of light has been introduced with a view to prepare the ground for observations of physical changes from the point of view of energy. The rapid growth of complexity along with progress is seen, perhaps too clearly, in the sections on 'Radiation,' and in the delicacy of the apparatus required. The optical bench is an involved and expensive piece of apparatus. For elementary work the outlay would be very disproportionate to its utility; but for advanced work

in optics it is indispensable, and it may be adapted for demonstrating the thermal properties of radiation. Only delicate manipulators should be allowed to use it, except under supervision. The wooden substitute described in Section 98 will, however, serve for many valuable observations, and will prepare the way for more accurate work.

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